ENCOURAGING SEDENTARY WORKERS' ACTIVE SEATING THROUGH PRODUCT DESIGN

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ENCOURAGING SEDENTARY WORKERS' ACTIVE SEATING THROUGH PRODUCT DESIGN

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

SUMMARY

The purpose of this project is to design a perturbation system for encouraging active sitting. This product would improve the physical environment within which the sedentary workers work and reduce their incidence of musculoskeletal discomfort. Specifically, the sedentary workers would be able to slightly shift postures without being disturbed by the device through an intervention, therefore, encouraging in-seat movement.

In this thesis, researchers first conducted a literature review about prolonged sitting and active sitting, then used participatory approach and human-centered design methodology to design and develop the prototype through workshops and testing. The aims of this project including evaluating the sitting experience, measuring sitting movement, designing the active seating prototype and prototype validation. Findings, limitations and future works were discussed in the conclusion.

CHAPTER 1. INTRODUCTION

In today's workplace, sitting has become a more and more common posture. According to Beach's report, three-quarters of all workers in industrialized countries have sedentary jobs that require sitting for long periods. People also have recognized the relationship between workplace factors and the occurrence of the lower back pain (LBP) (Beach, Parkinson, Stothart, & Callaghan, 2005). Observational studies show breaking up prolonged sitting has beneficial associations with cardiometabolic risk markers (Dunstan et al., 2012).

The purpose of this project is to design a perturbation system for encouraging active sitting. This system would improve the physical environment within which the sedentary workers work and reduce their incidence of musculoskeletal discomfort. Specifically, the sedentary workers would be able to slightly shift postures without being disturbed by the device through an intervention, therefore, encouraging in-seat movement.

The target user of this product is the sedentary office workers. This project focus on improving the office workers' sitting ergonomics and promoting the activing sitting of sedentary workers. However, the use case of this design should not be limited to only office workers. All the people who have prolonged sitting such as, truck drivers, students, and wheel chair users can be the target user of this product. So there is a design opportunity to develop the product in a more specific use case.

1.1 Problem Statement

The increasing degree of computerization over the past years had led to higher amounts of sedentary time and time spent in static postures, which can be associated with higher risks of chronic diseases, obesity and even mortality (Schwartz, Schrempf, Haller, Probst, & Glöckl, 2013). A series of metabolic health problems have been proved linking with prolonged sitting. Observational studies show breaking up prolonged sitting has beneficial associations with cardiometabolic risk markers (Dunstan et al., 2012).

Based on this discovery, many different interventions were invented to help users to break up prolonged sitting. Most of these devices follow two main ways of improving the sitting condition of sedentary workers which are breaking up prolonged sitting and active sitting. Active sitting is a concept that applies primary to chairs and stools that allow movement (TJ, 2013). The active sitting is to allow or encourage the seated occupant to move. And some intervention were invented based on this theory and were discussed in chapter 2 prior art review. However, the methods of preventing static seated posture are still not prevalent due to many different reasons. Both high price of the device and its increased discomfort and fatigue prevent users from dynamic sitting, as a result, sedentary workers tend to sit in a static position.

In this project, we developed a perturbation product which can improve the seated ergonomics of sedentary office workers. The product includes a polymer base, three bladders, pneumatic system and electronic control board.

1.2 Significance of the Study

In today's workplace, sitting has become a more and more common posture. According to Beach's report, three-quarters of all workers in industrialized countries have sedentary jobs that require sitting for long periods. People also have recognized the relationship between workplace factors and the occurrence of the lower back pain (LBP) (Beach et al., 2005).

LBP currently became an important public health problem in all industrialized countries. According to Lis's research, more than one-quarter of the working population is affected by LBP each year, with a lifetime prevalence of 60-80% and a large percentage of LBP claims for long durations (more than 90 workdays lost) (Lis, Black, Korn, & Nordin, 2007).

Because of the potential economic and social benefits to be gained from reducing the magnitude of LBP, it is worth to focus on the topic of improving the sitting condition of sedentary workers. Considering a large number of current sedentary workers and its increasing trend, there is a great demand for products and study of this kind. For the end users which are sedentary workers, this study will improve the seated ergonomics and prevent them from prolonged sitting. The finding of this study will promote the active seating without disturbing users' work. Thus, the users can achieve the healthy seating ergonomic without reducing their working efficiency. For the researchers, the study will help them access the sitting condition of sedentary workers as well as provide an insight into the method of evaluating the sitting behavior.

1.3 Objective and Specific Aims

The objective of this project is to design and evaluate an intervention, based upon perturbation, to improve the ergonomics of sedentary workers. Particularly, for this project, the goal is to design and develop a cushion to encourage the active sitting of the sedentary workers and improve in-seat movement. The product would promote the active seating through passive perturbation without disturbing users' work.

The first aim of this project was assessing the state of knowledge about active seating, including current interventions to promote active seating. Then the design criteria and specification for a passive perturbation system that encourages postural movement were established based on research. A prototype of perturbation system was designed and fabricated. Finally, the system was evaluated through testing for its ability to encourage postural shifts.

CHAPTER 2. BACKGROUND

2.1 Literature Review

2.1.1 Problem of Prolonged Sitting

The increasing degree of computerization over the past years had led to higher amounts of sedentary time and time spent in static postures, which can be associated with higher risks of chronic diseases, obesity and even mortality (Schwartz et al., 2013).

Prolonged sitting has been identified as a serious metabolic health problem due to several pathogenic mechanisms linking muscular inactivity to increased health risks: low energy expenditure, leading to accumulation of visceral fat and activation of low-grade systemic inflammation; impaired endocrine function of the skeletal muscle causing malfunction of several organs and tissues of the body and low shear stress followed by decreased anti-inflammatory and antioxidant responses (Grooten, Conradsson, Ang, & Franzen, 2013). Thus, maintaining a static seated posture is a risk factor for the health.

2.1.2 Current Solution and its Limitation

Several methods have been taken and tested to lower the risk of this sedentary behavior. Observational studies show breaking up prolonged sitting has beneficial associations with cardiometabolic risk markers (Dunstan et al., 2012). The result shows that interrupting sitting time with short bouts of light or moderate intensity walking lowers postprandial glucose and insulin levels in overweight /obese adults. Regularly interrupting sedentary behavior with activity breaks may lower this risk (Meredith C Peddie, Rehrer, Skeaff, Gray, & Perry, 2013). According to Meredith's research, regular activity breaks which involved walking for 1min 40s every 30 min is more effective than continuous physical activity which involved walking for 30 min between sitting for 9h. The results show the difference in decreasing postprandial glycemia and insulinemia in healthy, normal-weight adults. Other research also shows the benefits of breaking sitting time. (Thosar, Bielko, Mather, Johnston, & Wallace, 2015) mentioned that when light activity breaks were introduced hourly during sitting, the decline in FDM was prevented.

Another way of preventing static seated posture is active sitting. Active sitting is a concept that applies primarily to chairs and stools that allow movement. The active sitting is to allow or encourage the seated occupant to move (Dickin, Surowiec, & Wang, 2017). Based on this concept, many modifications have been made to various sitting surfaces. One of the modification to the traditional chair or flat seating surface is the addition of an unstable support surface (stability ball, cushion, foam padding). Incorporating movement into sitting as a way of reducing physical stress has been argued and tested by many articles. Dynamically changing the positions of the lumbar vertebrae and pelvis during sitting has been found to help reduce posture-related pain (TANOUE et al., 2016). The author believes that the dynamic balance chair may effectively help worker work continuously in seated postures with little fatigue. Dickin’s paper also compared muscular activation in trunk and leg under 3 different sitting surfaces: flat-firm surface, air-filled cushion, and stability ball. The results show that compliant surfaces resulted in higher levels of muscular activation in the lower extremities facilitating increased caloric expenditure.

However, some research also shows that the dynamic sitting is not that effective. Kieran’s article suggests that the dynamic sitting does not significantly change trunk muscle activation (O'Sullivan, O'Sullivan, O'Keeffe, O'Sullivan, & Dankaerts, 2013). In this article, seven studies are included. Five studies reported no difference in trunk muscle activation. Two studies reported the difference which associated with increased discomfort, increased fatigue and greater spinal shrinkage. And the absence of the backrest may be the main reason for trunk muscle activation rather than the dynamic sitting.

Wilhelmus' article suggests that less postural sway and less muscle activity were observed during the conditions that encourage active sitting, compared with sitting on a conventional office chair.

2.2 Prior Art Review

Specific sitting devices are designed to promote active sitting. Prolonged sitting has been identified as a serious metabolic health problem due to several pathogenic mechanisms linking muscular inactivity to increased health risks. Prior arts are reviewed to find different ways of active sitting promotion product. The United States Patent, Trademark Office website and Google Patent is used to search for patents from 1908 to present. Keywords used included "active sitting," "dynamic sitting," and "chair seat."

The Rocking Chair is the earliest patent selected and was issued in 1908 (A.Wanner.JR, 1908). It has some new and useful improvements in the traditional Rocking- Chairs. Although its main objective is not for promoting active sitting, the rocking chair inspired the initial idea of active sitting. This patent has been cited by many later patents which topic is related to active sitting.

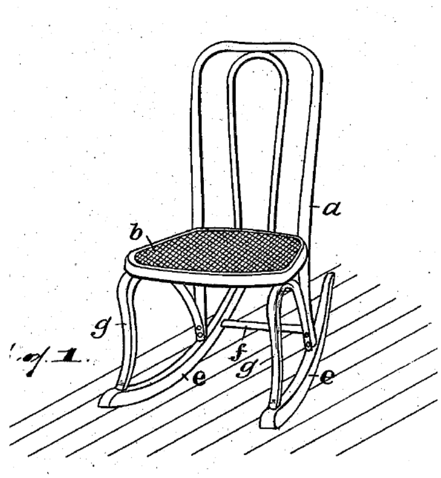


Figure 1 - The Rocking Chair (A. Wanner. JR, 1908)

The Spring Support Chair has for its principal objects to provide a spring supported chair or seat that is readily yieldable to accommodate itself to size, shape, weight and movements of the occupant; that will produce a rocking, tilting, bouncing when the occupant sways his body or presses his foot against the floor. This invention allows the user to change their position while sitting. But the contact area between the butt and the chair has not been changed in this case (A.E.Johnson, Feb.26 1952).

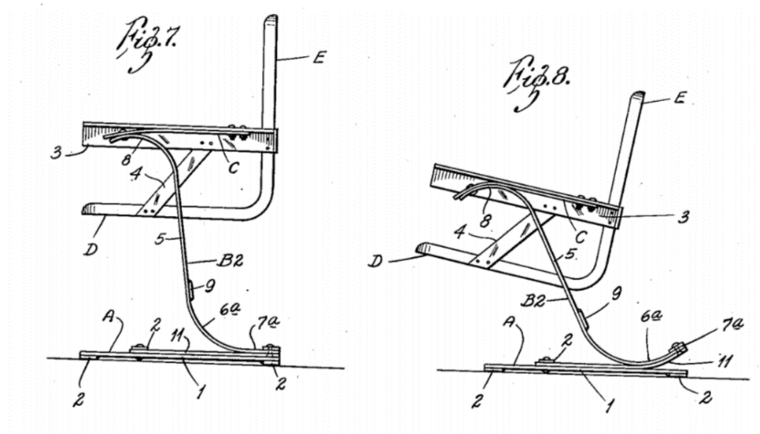


Figure 2 - The Spring Support Chair (A.E.Johnson, 1952)

Another patent that focused on moving seat is the active dynamic seat (Glockl, Mar. 23, 1995). It has a base, an intermediate piece linked to the base and a seat part linked to the intermediate piece. The seat part can tilt in all lateral directions and is linked in an essentially fixed manner in the vertical direction to the intermediate piece. The invention is based on the task of creating an active dynamic seat that can be produced in a simple and economical way.

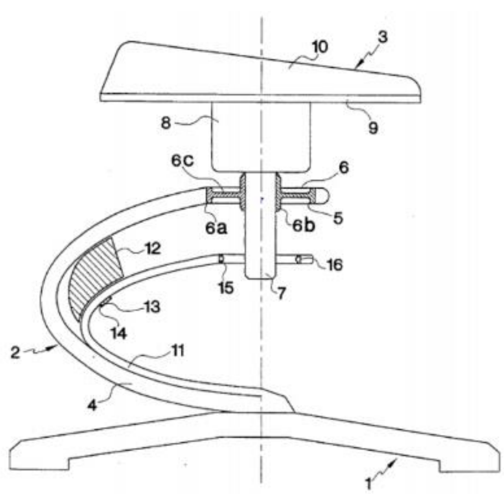


Figure 3 - Active Dynamic Seat (Glockl, 1995)

The Time-Out Chair/Seat comprises a seat member configured and dimensioned to accept a child in a sitting position (McDonald, Nov. 4, 1997). A timer is provided for timing a preset time-out period. Although this device does not provide a direct way of active sitting promotion, it can still be used to stop by prolonged sitting by using the time out.

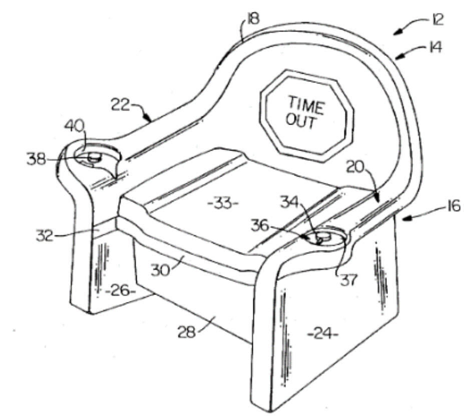


Figure 4 - Time-Out Chair (McDonald, 1997)

The dynamic posture chair is an invention which is filed in 1995 (Allard, May 20, 1997). It is capable of use in a range of sit/stand positions. This chair includes a mobile base that is selectively movable by the user and the chair member to be selectively and infinitely tiled over a predetermined of tilt position. The angle between the back and seat can be about 120 degrees to 135 degrees. The limitation of this device is that it can only tilt in the back and forth direction. Moreover, the movement of the back is promoted. However, the butt movement is limited. The pressure on the butt and leg may not be changed.

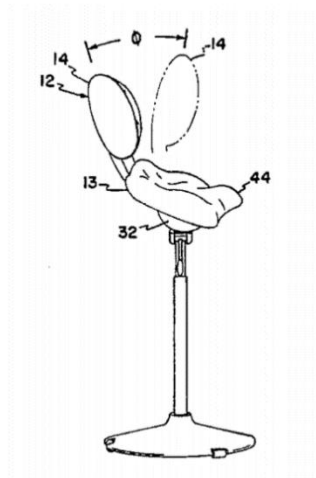


Figure 5 - Dynamic Posture Chair (Allard, 1997)

Active seating cushion is another way which provide a cushion which active seating capacity. The cushion having a sitting portion and a rigid material to maintain the sitting portion. The type of movement encouraged by active seating permits one to remain sitting while alternating weight from the left to right, thereby preventing the creation of sustained mechanical stress points. The benefit of this design is that it can fit different kinds of seats. User can easily attach this device to any other seats and gets a similar outcome. However, according to some research, long time sitting on this kind of device may related to fatigue.

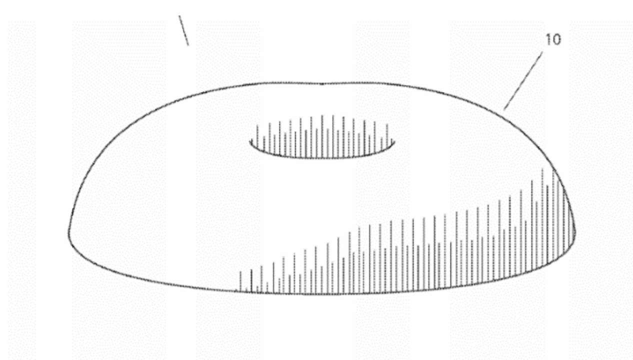


Figure 6 - Active Seat Cushion

The Ergonomic anti-fatigue seating device is an invention that can lift first one hip of a seated person and then the other periodically (Harza, Jun. 11, 1991). The main goal of this invention is to simulate the muscle stimulation and relaxation. It uses inflatable air bags to provide lift and the timing and distance of inflation is controlled by the control unit. This patent makes no distinction between hips and legs. It produces the support in a left and right direction. Also, the back and hip supports are provided by this device. However, the specific duty cycle and the bladder configuration were not defined in this patent. As a seating, this device has large volume and is not portable.

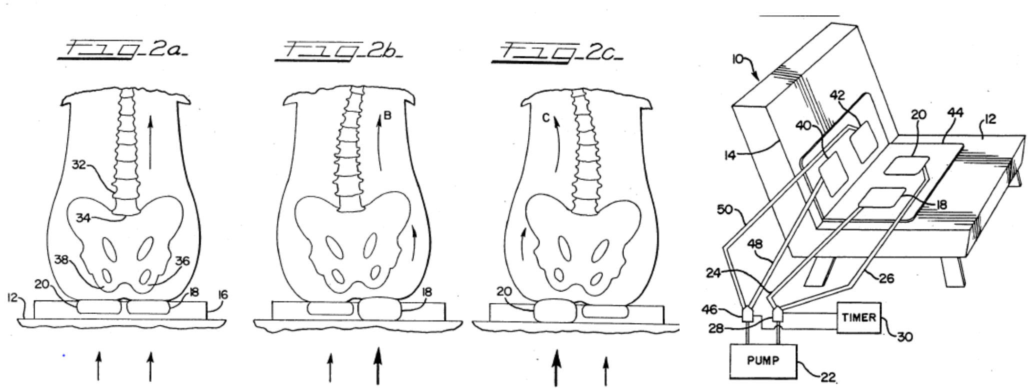


Figure 7 - Ergonomic Anti-fatigue Seating

The sitting device invented by Alexei Bykov can be used as a work chair or therapeutic furniture (Bykov, Jun. 17, 2008). The main goal of this device is to efficiently relieve the backbone. Each part of this seat can be adjusted by the rotational adjusters. This device provides separate supports on both the back and hip. However, the device requires the users to operate, which is not self-adjustable.

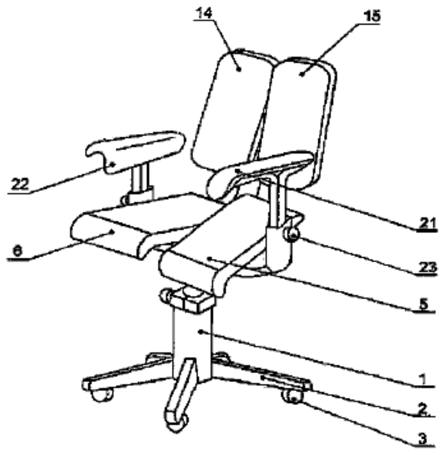


Figure 8 - A Work Chair (Alexei Bykov)

2.3 Gaps in Background Research

The prevalence of prolonged sitting and its related healthy problem has been proved. And all the solutions are proved useful in some parts but also have their limitation. Current studies point out that active sitting is more effective to the lower extremities than the upper extremities. If a design based on the active sitting can also encourage the movement of upper extremities, it may be more useful. On the other hand, some studies reported that active sitting is associated with increased discomfort and fatigue, which may become the design trade-off. But the specific reason of that still needs to further research. Last but not least, current interventions that promote the active sitting can only react to the body movement passively. The effectiveness of the perturbation system that encourages postural movement still need to be explored.

All the current devices on the market have their own limitations. For example, most of these devices have large volume and weight. Hence it's not convenient in many conditions. On the other hand, it's hard for those office workers to make a decision to replace their office chair with an active seating chair. Not only the high price of these devices but also how to deal with the previous chair can cause a headache. The active cushion provides a reasonable alternate solution although its promoting active seating function can't be shut down which might cause fatigue.

CHAPTER 3. DISCOVERY AND DESIGN METHODOLOGY

One purpose of this thesis is to establish design criteria and specification for a passive perturbation system that encourages postural movement. To fulfill this objective, typical sitting behaviors of sedentary workers were observed and documented.

This section starts by accessing the sitting behavior of sedentary workers work at their workstations. Specifically, the types of chair they user, their normal sitting time, the distribution of sitting pressure and their specific movement during long time sitting were documented. This part laid the foundation and provided the insight for designing better seating design options.

3.1 Sitting Environment of the Normal Sedentary Workers

In order to begin designing a device that can improve the seated ergonomics of sedentary workers, one must first discover the typical sitting environment of sedentary workers which starts by measuring the workstation. This study took place at Georgia Institute of Technology in the REAR Lab. The workstation used in the lab was observed. This pilot study provides more understanding of the working environment and does not collect any personal information.

Measuring the chair can provide useful information. However, it would be better if the office chair & workstation are considered as a whole. The dimension of the desk and the monitor help us better understands the working condition and work posture of a normal sedentary worker. The chair used in this research can be seen below in Figure 9. A copy of the chair measurement guild line can be found in Appendix A.

Figure 9 - Side view of the chair used in the research

The office chairs used in Georgia tech REAR lab are the same products made by Steelcase. This provides consistency while doing the following testing since different offices chair may cause discomfort or stimulate the users to react differently.

This office chair is an adjustable chair which allows a user to adjust the armrest height and seat height as well as the distance between arm-rest. The material of the chair seat is polyurethane leather and the backrest is made of nylon fabric. The chair has five wheels which are easy for users to adjust the position of their body. The result of measurement is shown below in Table 1.

Table 1 - The chair measurement result of office chair

Part Name	Size	Part Name	Size
A: seat height	17.5-21.5in	A: the height of the desk	28.5in
B: seat deep	19.5in	B: the depth of the knee	NA
C: seat width	20in	G: eye height	NA
D: backrest height	23.5in	H: view depth	NA
E: backrest width	19in	F: object height monitor	37.5in
G: armrest length	5-9in		
H: armrest length	9.5in		
I: distance between arm length	19-22in		
J: seat to back angle	110deg		
K: seat- angle	4deg		

3.2 Sitting Behavior Observation

To further analyze the sitting behavior of sedentary workers, their specific postures during sitting need to be recorded. Based on the researchers' observation, the sedentary workers normally have such typical postures: upright, front lean, back lean, side lean and leg crossing. The posture sketch is showed below in Figure 10.

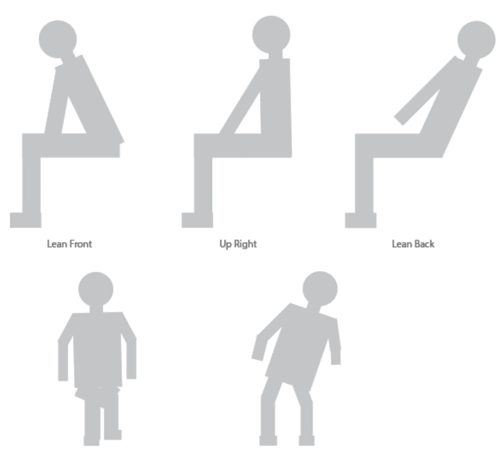


Figure 10 - Typical posture user behaved during observation

3.3 Different Sitting Behavior Pressure Distribution using FSA sensor mat

For better understanding the pressure distribution of the subjects while sitting. Researchers used FSA seat sensor as a mean to assess sitting pressure data. Knowing the pressure distribution difference between each posture could provide useful information on how people sit and how they shift their postures.

The study used a hardware that collects and store activity information. A thin sensor mat was placed on the top of the chair to measure forces at the seat interface. During the testing, researcher performed all five postures through and took the screenshot of the pressure distribution. Since the sensor generates a large amount of data, this method is only used to collect short-term sitting information in this case. The testing result can be found in Appendix B.

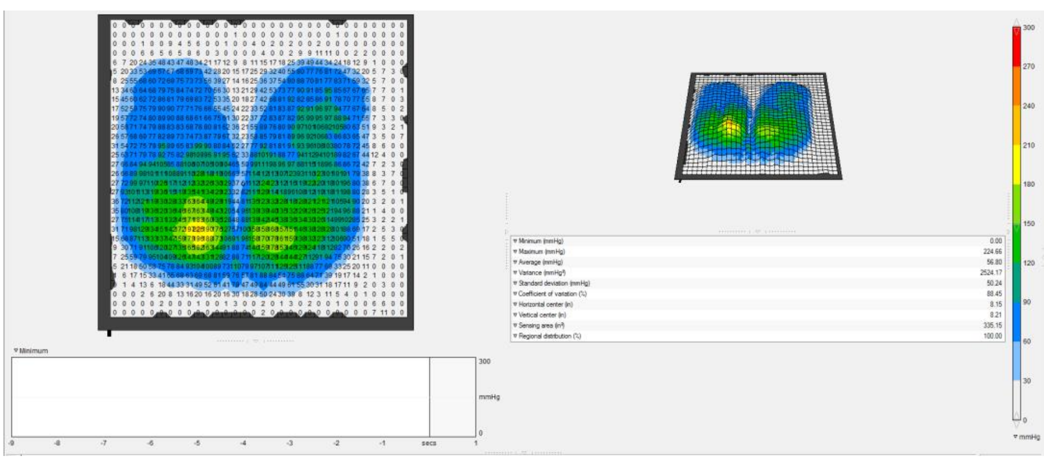


Figure 11 - An example of the FSA testing result

Results showed that when subject switches posture, the pressure distribution changes along. And if the subject leans side or crosses leg, the high pressure under the buttocks can reach over 300 mmHg. Except lean forward, other postures did not generate much pressure on the thigh area. The results prove that subjects' sitting behavior can be monitored by using pressure sensors.

3.4 Pilot Study 1: Long Term Measurement of in-seat Movement with Seat Sensor

FSA testing result proves the validation of using a pressure sensor to monitor sitting behavior. However, the method generated a large amount of data which may not suitable for long-term testing. A new method needs to be established which aims at knowing the pressure distribution of the subjects during long-term so as to further figure out the subjects' postural change during long-term sitting.

Within this study, the in-seat movement will be measured as a mean to assess active versus quiescent sitting. Developing distributions of in-seat movement is the first step needed to begin setting activity goals and objectives that are consistent with good ergonomic outcomes. Using seat sensor here is because it generates fewer data and is easy to process for long-term study.

3.4.1 Procedures for data collection

The study used a hardware that collects and stores activity information and an analysis system capable of detecting in-seat movement during sitting. The hardware system consists of a data logger and seat sensor. The data logger is able to measure and store in-seat movement for at least 2 work days. It will be mounted underneath the seat surface. It is also designed to avoid impacting the participant's seating environment or daily activities in any manner.

A thin robust sensor was placed on top of the chair surface to measure forces at the seat interface. The sensor consists of 6 individual force sensors arranged in a 2 x 3 array. Conductance of the sensors changes with applied load in order to measure in-seat movement. Sensors will be connected to a data logger which measures the voltages for each sensor. A 1 cm thick elastomeric pad is placed on top of the sensors to create a uniform sitting surface and to isolate the sensor pad.

Data collection commences with a short initialization procedure that is required to properly configure the system to the individual. The subject was asked to sit on their office chair onto which the seat sensor had been added and adjust the chair as necessary. The study recruited two subjects and both of them sat on the sensor for two sessions. Each section took two hours and was conducted on different days.

Figure 12 - Seat sensor used for long term pressure distribution data collection

3.4.2 Measurement Results

Figure 12 shows the pressure change of each sensor during the two hour of subject 1 in first round sitting. The total force dropped dramatically three times which indicates that the subject left the seat for three times. This provides an insight on using pressure sensor to monitor subject's occupancy.

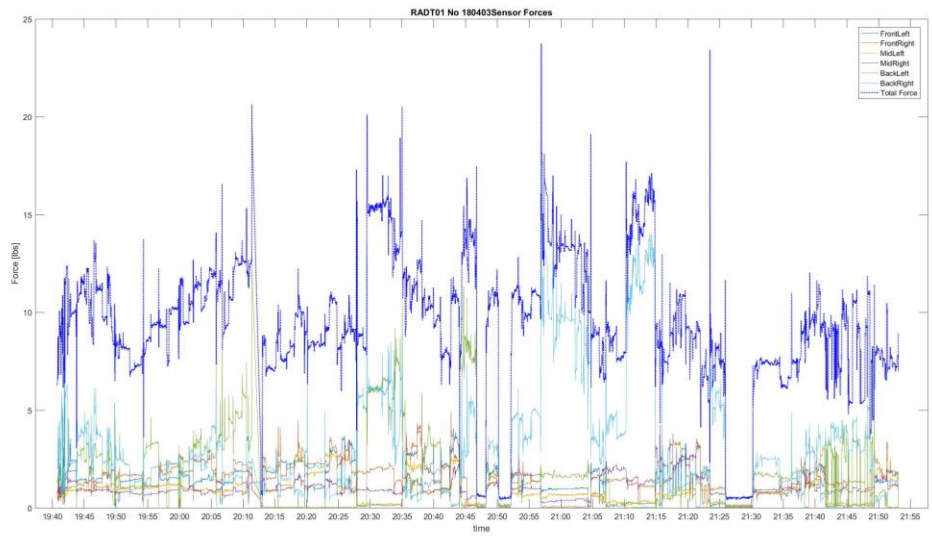


Figure 13 - Pressure change of each sensor during two hour sitting

Figure 13 shows the center of pressure movement during the testing. It was calculated based on the change of pressure. However, the data includes too much noise and there are few research on defining postural change with COP, how to utilize the data still need further developing.

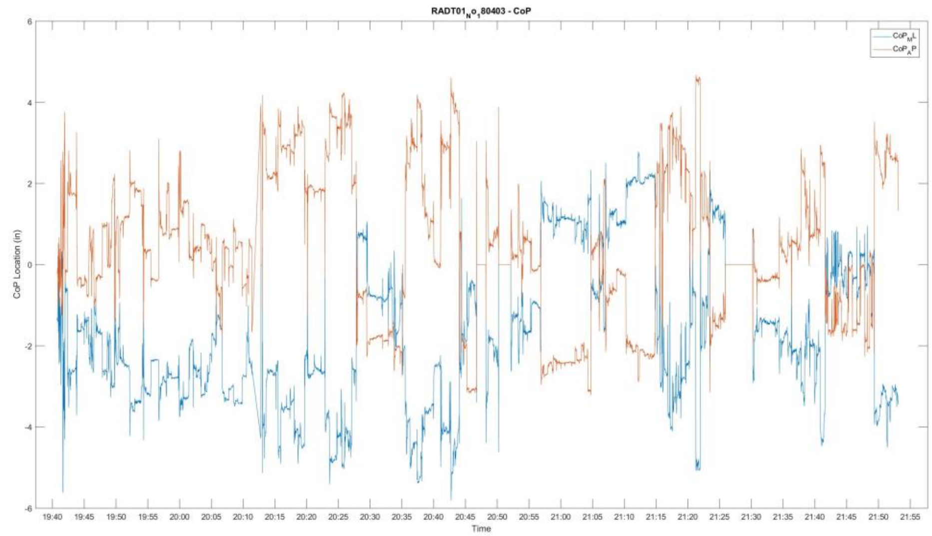


Figure 14 - Center of pressure movement during the testing

3.5 Pilot study 2: Measurement of in-seat movement with accelerometer & pressure sensor

3.5.1 Test preparation

This pilot study aimed to validate the method of using an accelerometer & pressure sensor to measure in-seat movement. During the testing, subjects were asked to perform a series of in-seat movement. Researchers used accelerometer & pressure sensor to document all these movements and use a computer program to analyze the data collected by the sensor. Then researchers compared the test result with the subjects' required movement to validate its correlation.

During the test, an accelerometer was placed over the sacrum at the level of S2 of the subject (Figure 15). A pressure sensor mat was placed on the chair under the subject.

Researchers would open the seat pressure sensor and the accelerometer first. Then the subject would be asked to sit on the office chair and adjust the chair to its comfort level.

Figure 15 - Accelerometer placed over the sacrum

The subject first performed sit straight for 20 seconds. Then he would be asked to lean left, lean right, lean forward and lean back. Subjects would stay in each position for 20 seconds. There would be five seconds time gap between position transitions. After these, the subject would be asked to sit straight for 20 seconds. Then he would stand up and leave the seat.

3.5.2 Test result

Figure 16 shows the pressure change detected by all six sensors. The red line indicates the seat occupied condition. If the total pressure on the seat sensor is lower than 200, which means the subject is not on the seat and that part of accelerometer data will not be included.

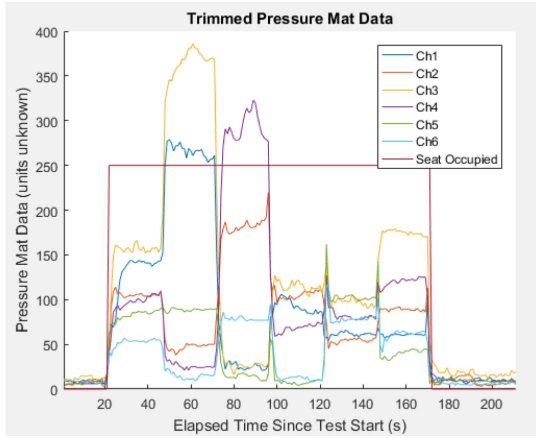


Figure 16 - Pressure sensor data

Figure 17 shows the pitch (front& back) angle and roll (right & left) angle of the subject. This data automatically excluded the time when the subject is not on the seat. Subject's behavior is well reflected on the sensor. Each postural change is indicated on the figure by small round dots. This study validated the method of using an accelerometer & pressure sensor to measure in-seat movement.

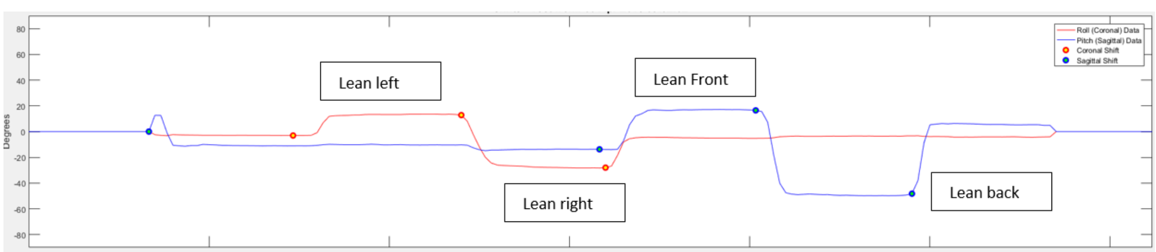


Figure 17 - Postural change indicates on the figure of roll& pitch angle change

CHAPTER 4. CREATIVE EXPLORATION

4.1 Concept Development

When exploring possible solutions to the issue of preventing prolonged sitting with a perturbation system which can promote active sitting, there are three main avenues to investigate:

1. A perturbation cushion which can invoke postural change
2. A chair that has moving parts which promote active sitting
3. A special device which uses a reminder-based technology

Based on the previous prior art review, all these three concepts have some design foundation and warranted further exploration. For the second concept, the potential to viably manufacture of this kind of device is low. Since a mechanical mechanism is neither easy to prototype nor cost-effective. Designing an ergonomic chair which can promote active sitting takes a long time to develop. For the third concept, the most common way is designing a reminder-based technical device. However, in order not to disturb the subjects' normal working, this method might be hard to achieve the design criteria.

The prior art shows that a portable cushion which can be attached to most kind of office chair will be a promising market. First of all, current products on the market all come with the seat. However, the functional part of a chair which can invoke postural change is not necessarily tied to the chair itself. A portable perturbation system can create large freedom for the target user while choosing such kind of device.

4.2 Overall Concept

The basic concept is a thin pneumatic pad with three bladders sections. This pad can be used to induce slight postural perturbations using changes in internal air pressure. An inflation sequence will be defined that fills the bladders-one at a time- to slightly shift posture without disturbing the seated individual's work activity. The bladder should reflect the anthropometry of the pelvis while having a form factor to fit on a regular office chair. Figure 18 shows the concept of this device.

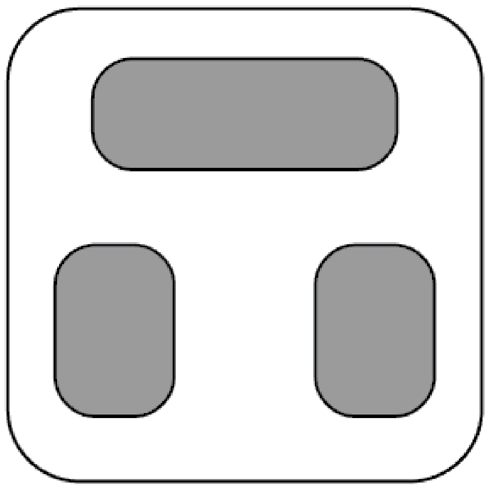


Figure 18 - Overall concept of the three bladder pneumatic pad

4.3 Design Criteria

Now that the overall basic concept direction was established, a design criteria table were created (Table 2).

Table 2 - Design criteria table for the overall concept

D/W	Requirement	Source
	Geometry	
D	System width < 40 cm	=average chair seat width (40cm)
D	depth< 40 cm	= average chair seat depth (40cm)
W	Thickness < 1.5 cm	
W	Electronic package fit into cushion	Package include pump,controller,valves
	Aesthetic	
D	Modern office furniture aesthetic	Target user: office worker
	MASS& ratings	
D	Inflatable weight capacity: 111.58kg	95th percentile male weight USA
W	Device weight :3Lbs or less	
	Energy	
D	If use AC power: plug to standard wall socket	
D	If use battery: life > 10 hr	Full day of use
	Ergonomics	
W	Fit the ergonomics of human body	Based on anthropometry
	Operation	
W	Provide a perturbation system for user	Perturbation helps people shift weight
D	Full Automatic control	
	Cost	
D	Sell for < 300$	Marketing spec
D	Manufacture for <50$	Marketing spec
	Safety	
D	Air bladder: Max pressure >55kpa	12V air pump Max pressure
D	System voltage < 24V	maximum safe dc voltage
	Materials	
D	Removable cover	
D	Cover: resistance to dirt	
D	Bladder: air tight & water tight	

4.4 Prototype Development

The whole system can be divided into two parts, which are the pneumatic system and the electronic parts. The electronic parts include an air-pump, a controller, and several solenoid valves. This part provides the air supply for the bladders as well as control the pressure of bladders and gives the right inflation timing.

The micro control unit controls the pump and valves which are connected to the pneumatic part. The pneumatic part includes three bladders which are placed on the base and packaged by fabric. This part allows the cushion to inflate and deflate and creates perturbation which encourages users to shift their weight.

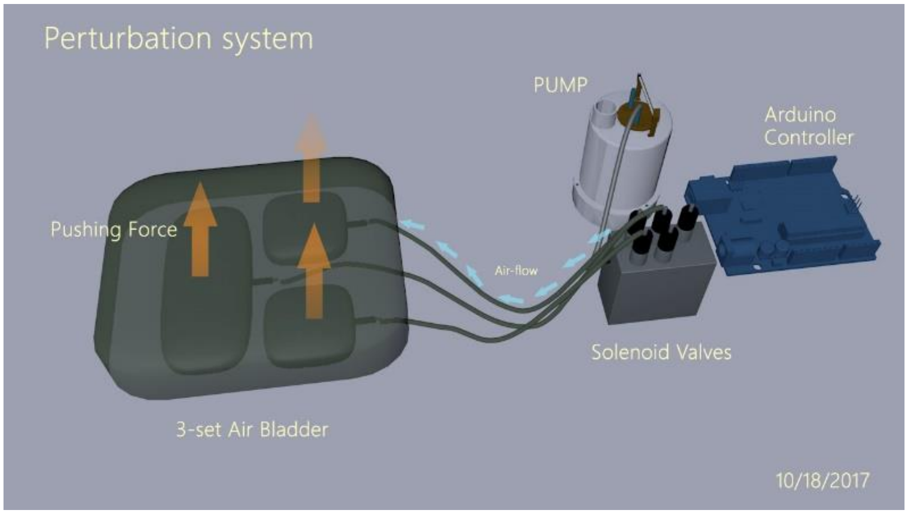


Figure 19 - Rendering for the 3-set air bladder basic concept

4.4.1 Electronic Parts Developing

In this case, the Arduino SparkFun RedBoard is chosen as the controller for the whole system. The reason is that it works well for prototyping and is compatible with most of the sensor. The main function of this prototype is to inflate and deflate three bladders.

The system uses four valves because three valves are used to control the separate bladders and the last one is used to control the deflation. The system also includes a motor (air-pump). All these components run at 12V which means they can't be controlled directly by Arduino since it runs at 5V. A specifically designed motor shield is introduced here and its circuit diagram can be found in Appendix C. It uses the uln2003a chip which is shown in Figure 20.

A pressure sensor is added to the system which can detect the inner pressure of each bladder. The inflation time is based on the pressure of the bladder. If the pressure reaches the set goal, the pump will stop inflating the bladder and shut down the valve. The pressure sensor is shown in Figure 21.

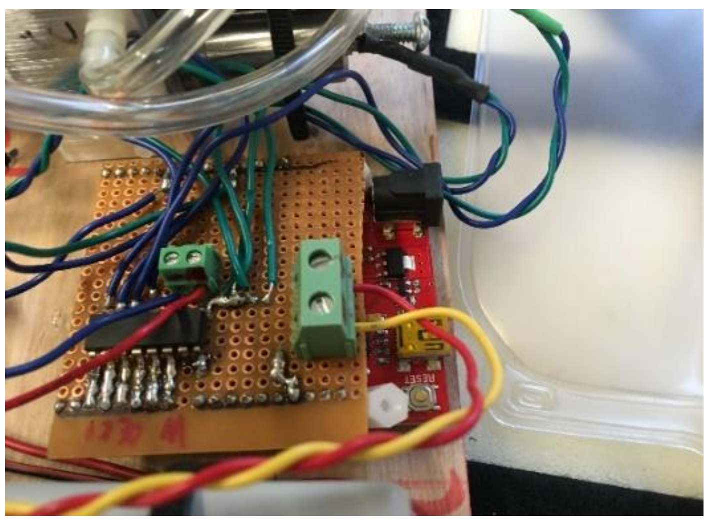


Figure 20 - The uln2003a chip

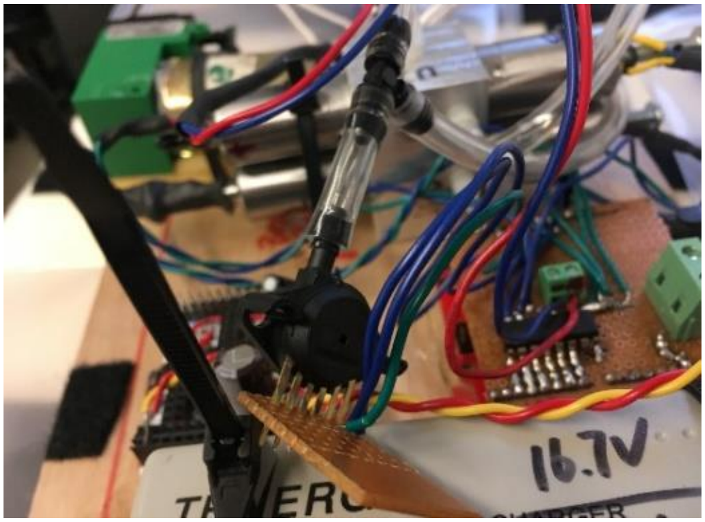


Figure 21 - Electronic components of the micro-control unit

4.4.2 Pneumatic System Connecting

The inflation and deflation of each bladder is control by the solenoid valves. Four solenoid valves are installed on a customized manifest. All the four intake ports of these valves are connected to the pump and they have separate outtake ports. The valve can be activated by 12V Dc power. Since the original manifest produced by the manufacturer only supports three valves, a customized manifest which can hold four valves is made.

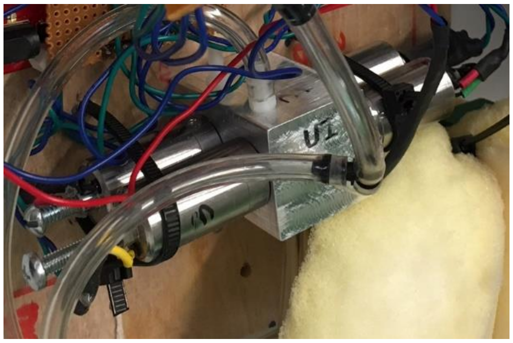


Figure 22 - Solenoid valves and manifest

4.4.3 Bladder Designing and Fabricating

Since the pneumatic connecting system had been done, the next step is making the bladders for the system. Based on the design criteria set previously, the maximum pressure of the bladder should be larger than the pump's ability due to the safety factor. In this case, the pump's maximum pressure is 55 Kpa. The bladder has two parts, which is the bladder and the port which is used for a connection.

The first quick prototyping for this design used the IV bags as the bladder. The prototype is shown in Figure 23.

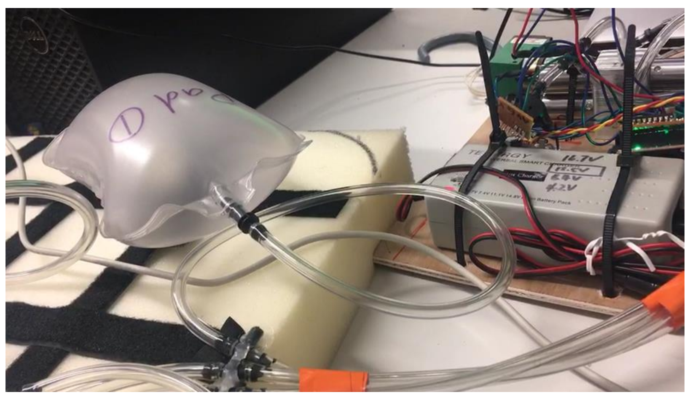


Figure 23 - Prototype using IV bags as bladders

The IV bag used in this prototype is made of PVC and use high-frequency welding to seal. The testing maximum pressure is 70Kpa. According to the general recommendation, the factor of safety for use with ordinary materials where loading and environment conditions are not severe is from 1.5-2. The IV bags used as a cushion bladder did not meet the safety standard. On the other hand, the shape of the inflated IV bags is dome-like. A shape of this kind doesn't work for this project since it's both hard to control the desired height of the bladder and difficult to control the contact part of subjects. If users sit on the side of the dome shape bladder, the direction of perturbation is unsure. Lastly, the PVC IV bags have poor material fatigue which causes the declination of the durable.

In order to overcome these problems, the second prototype chose to use heat sealable nylon fabric. It's a lightweight fabric which has two layers of fabric. The first layer is nylon which provides the strength and the second layer is Polyurethane which seals the air. It's easy to work with a heat sealer and can meet the design criteria.

To restrict the shape of the bladder, several ribs are added on both sides. The rib use same material as the bladder which is TPU. It's attached to both sides of the bladder and restricts the bladder's height. After the bladder is inflating, it remains the cube-like shape which is shown in Figure 24.

Figure 24 - The second version of bladder which maintain the cube-like shape

After the bladder was fabricated, the next question is the port. The first model used a 2- inch long PVC-pipe which located on the top of the bladder. The second model used a specific vinyl port which is installed on the side of the bladder. The detail of the structure is presented as Figure 25.

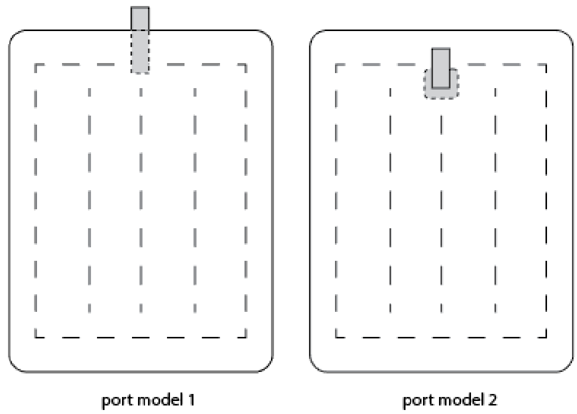


Figure 25 - Structure of two different ports

Both of these two types of bladders were fabricated and tested. The result turned out that the first model bladder can stand for at least 100 KPA while the second one can stand for more than 210 KPA. The crush part of the bladder is the connection of the port and bladder, which is glued together. The reason for first bladder's tearing apart might be the less glue area. So, in this case, the second one was chosen because it can seal the bladder better and withstand higher pressure.

Figure 26 - Two types of bladder ports prototypes

4.4.4 Bladder Packaging

After the bladder was fabricated, the next step was bladder packaging. Since the pipe and port used for connection were made of PVC which might be intrusive for user, some kind of base cover can help reduce that. The first one is made of foam and the second one is made of polymer. The thickness of the foam is 1 inch and the thickness of the polymer is ¼ inch. The size of the cushion is depended on the size of the office chair. The design guideline should follow these rules.

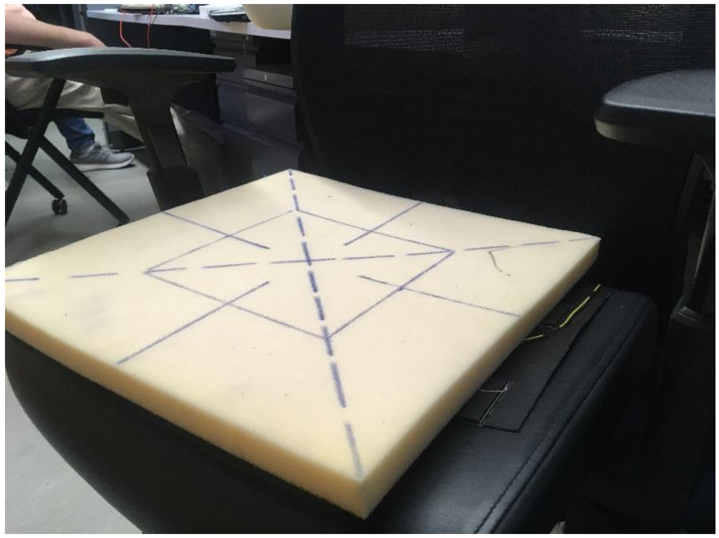


Figure 27 - Foam base using for bladder

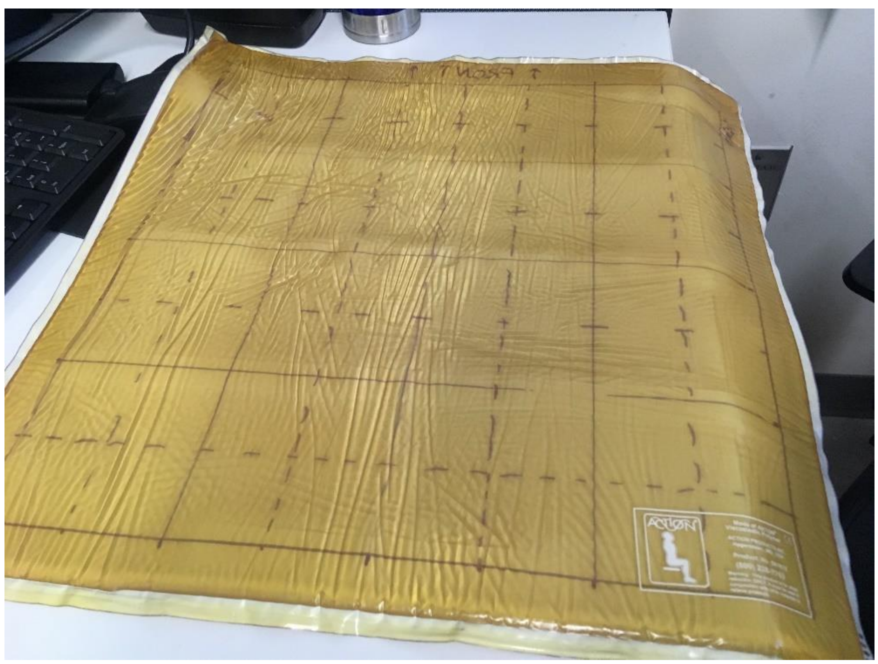
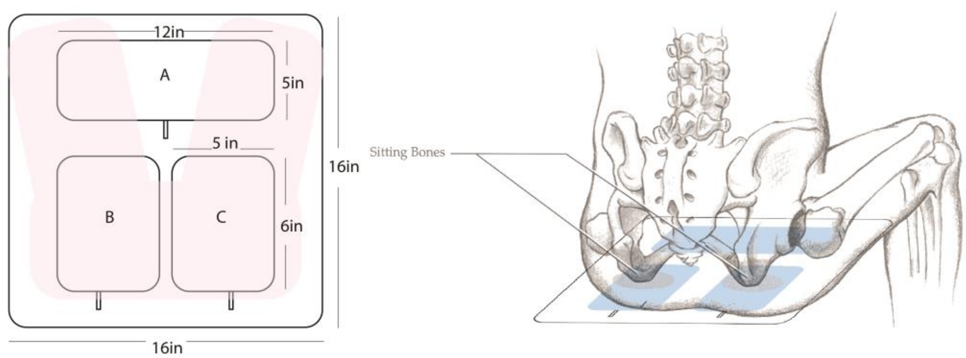


Figure 28 - Elastomer base using for bladder

4.5 Iterations

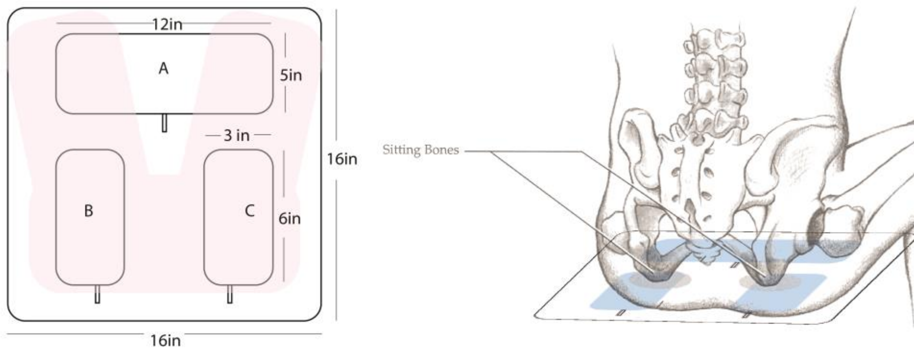
How to arrange the location of the bladders and decide the size of the bladders was the next question. According to the overall concept, there would be three bladders placed on the cushion. The location of the bladders on the cushion can be decided by the body contact part. Three configurations of bladder layout were designed follow this rule. The size of the base is 16in by 16in which can normally fit all the office chair.



The first design has three bladders ,which are one thigh bladder and two buttock bladder.
Bladder A and B located under the sitting bones and great trochanters.

Design Configuration 1

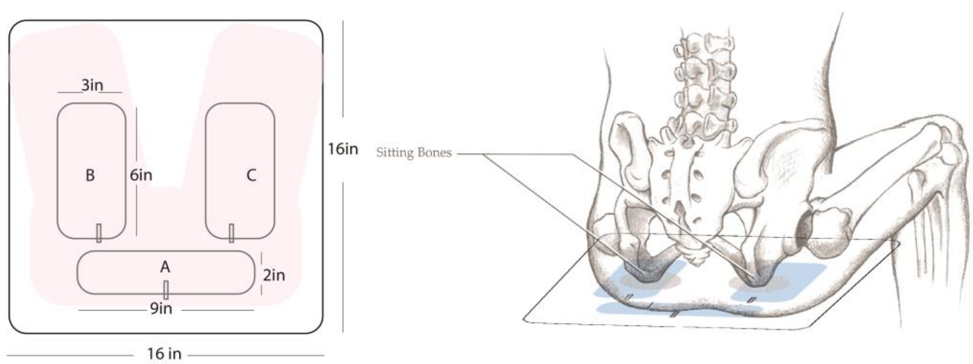
Figure 29 - Design Configuration 1



The second design separates the buttock bladders. Instead of giving a direct straight force this design aims to create the effect of budging the subject.

Design Configuration 2

Figure 30 - Design Configuration 2



The third design has one sacral bladder and 2 buttock/ thigh bladder.

Design Configuration 3

Figure 31 - Design Configuration 3

4.5.1 *Bladder Fabricating*

After the bladder layout is designed, the bladders are fabricated based on the layout (Table 3).

Table 3 - Bladder layout for fabricating

	Size (in2)	Thickness (in)	Usage
thigh bladder	12*5	1	Configuration 1 (A)
sacral bladder	9*2	1	Configuration 3 (A)
buttock bladder	6*3	1	Configuration 2 (BC)
buttock bladder	6*5	1	Configuration 1 (BC)

The bladder is made of TPU fabric. It's a waterproof TPU laminated fabric. It's widely used for inflatable life jackets, raft, inflatable boats, inflatable tents. There are quite a lot benefits using this to make bladder. First of all, it's waterproof and airtight. The second reason is that it can provide higher air pressure than other PVC bladders such as IV bags. Thirdly, the material is easy for prototyping which can be made with a heat sealer. After the bladders are making, Velcro is attached to the back of the bladder so that it can be put on the base cushion.

Figure 32 - Bladder Fabricating

4.5.2 Bladder Pressure Setting

The main goal of the bladder is to let people shift their weight without disturbing them. To achieve this goal, the first thing to do is to calculate the inner pressure of the bladder. Table 4 shows the relationships between the force which bladders can create and the inner pressure. According to the size of the bladder, the inner pressure is calculated based on the lift force it can create. For example, when the inner pressure of a 12*5 square inch bladder is 105.9 KPa, it can lift a 40Lb object.

Table 4 - Bladder pressure setting

	178 N (40lb)	133.5 N (30lb)	88.9N (20lb)
size	Pressure(abs) A	Pressure(abs) B	Pressure(abs)C
12*5	105.9	104.7	103.6
9*2	116.6	112.8	108.9
3*6	116.6	112.8	108.9
5*6	110.5	108.2	105.9

4.6 Short Term Usability Trial: Different Configuration Evaluation

To further develop the product and choose the best configuration of the product, researchers conducted a short term usability trial. In this study, all three bladder positions and two cushion bases were evaluated. This study aimed at finding the best configuration which can satisfy the user most also providing insights for design refinement.

The study recruited 8 subjects in Georgia Institute of Technology. 8 subjects, includes 3 females and 5 males, participated in the study. The results are presented in next section 4.6.1. The test took place at Georgia Institute of Technology REAR Lab. The prototype used in this test includes three configurations of bladder designs and two cushion bases. Other facilities used included an office chair and workstation. The photo of the prototypes is shown in Figure 33. The questionnaire used in this study can be found in Appendix D.

Figure 33 - Prototype used in group study

The first round study aimed at finding the most comfortable bladder configuration. Researchers first introduced the process of the testing and gave a brief introduction to the project. After that, subjects were asked to sit on the office chair without a cushion for five minutes. This process gave the subject an idea of the comfort level of a normal office chair. After that, subjects were asked to sit on the prototype with one of the configurations. The specific configuration was picked randomly to minimize the influence of testing order. During the sitting, the prototype activated the pump and the bladders were inflated and deflated. Subjects could stop the process and proceed to the next once they had a clear idea on this configuration. After all three configurations had been tested, subjects were asked to rate the comfort level of the prototype according to the questionnaire. They could also give comments if they want. The result of this round of testing is show in 4.6.1. Table 6 shows the score of each design. Design A marked the highest score and would be used in the next round testing.

Based on the results of the first round, second round study evaluated two types of the cushion base which are foam base and polymer base. The subjects were asked to complete two rounds of testing. For each round, the subject was asked to settle the cushion first then sit on the cushion for 5 minutes. During this time, the bladders were inflated and deflated two rounds. Then the subjects were asked to complete a part of the questionnaire to evaluate the comfort level, effectiveness and usability level of the cushion. The testing cushion was set with two different types. The configuration will be randomly ordered for sitting tasks. The process of this part study is shown as Table 5.

Table 5 Process of evaluating the configurations

Round 1	sit on the office chair without cushion	
	settle the cushion on the office chair	
	sit on the cushion with the bladder on	5min
	remove the cushion from the chair	
rest	evaluate the cushion	
Round 2	sit on the office chair without cushion	
	settle the cushion on the office chair	
	sit on the cushion with the bladder on	5min
	remove the cushion from the chair	
rest	evaluate the cushion	

4.6.1 User feedbacks, Survey result and Conclusion

Table 6 - Results for rating the comfort level of 3 configurations of bladder design

Subject N.O	Gender	design 1	design 2	design 3
1	F	2	4	3
2	M	5	2	4
3	M	5	4	2
4	F	3	4	2
5	M	4	4	3
6	M	5	4	2
7	M	4	3	4
8	F	4	3	2
total		32	28	22
score		4	3.5	2.75

For the testing results, score 1 represents "Very uncomfortable", score 2 represents "Somewhat uncomfortable", and score 3 represents "neutrals", score 4 represents "Somewhat comfortable", score 5 represents "Very comfortable"

Besides the score, subjects also provided comments on these three designs.

comments		number of people
1)	big bladders in front felt weird, but not bad	1
2)	bladder under tail bone feel weird	3
3)	bladder touch Sacral makes me feel uncomfortable	1
4)	Design B 's small bladder is bit jarring	1
5)	The pressure of buttock bladder is a little bit too strong	1

Based on the testing results, among the 3 designs, the design A marked the highest score and would be chosen for further product development.

Table 7 - Results for rating the usability, comfort level and effectiveness of two cushions

		FOAM CUSHION			GEL CUSHION		
No.	Gender	usability	comfort	effectiveness	usability	comfort	effectiveness
1	M	4	4	2	4	5	2
2	F	4	4	2	3	3	3
3	M	4	5	2	4	5	2
4	F	4	5	3	2	3	3
5	F	4	4	2	3	5	3
6	M	4	5	2	4	5	2
7	M	4	4	2	4	5	3
8	M	4	4	2	3	5	2
total		32	35	17	27	36	20
score		4	4.375	2.125	3.375	4.5	2.5

For the testing results, score 1 represents "Very uncomfortable", score 2 represents "Somewhat uncomfortable", and score 3 represents "neutrals", score 4 represents "Somewhat comfortable", score 5 represents "Very comfortable" Score 1 represents "None shift", score 2 represents "small shift", and score 3 represents "large shift" Score 1 represents "Very inconvenient", score 2 represents "Inconvenient", and score 3 represents "Somewhat convenient", score 4 represents "Convenient"

It can be concluded from these testing results that all of the eight subjects considered that the foam cushion's usability is somewhat convenient while the polymer cushion was only rated as neutrals. The total scores of the comfort level were similar. However, except two users rated the second one as neutrals, others all considered it as very comfortable. This result shows that there is a high chance these users willing to purchase the second product. The second cushion also performed better in the effectiveness test. Since the usability of the cushion is less important than the other two factors based on the fact that people don't move their cushion very often, the second cushion with the polymer base was chosen for further developing.

4.7 Duty cycle of the bladder inflation

For the final prototype, the pneumatic system and the electronic system had been connected and tested. The bladder and the polymer base had been assembled then packaged with the space foam. There was another issue still remaining to be solved, which is the duty cycle of the bladder inflation.

Breaking up prolonged sitting has positive effects on health. The perturbation system promotes the active sitting through bladder inflation. However, the specific duty cycle the system should run at was still not clearly defined. In other words, the effective frequency of breaking up prolonged sitting was important for the system.

Based on the literature review, 2-minute bouts of either light-intensity or moderate-intensity walking every 20 minutes had a significantly positive effect on lowering systolic blood pressure in overweight and obese adults who sit 7 hours a day (Dunstan et al.). Husemann et al. reported that standing for 15 minutes doing non-data-entry office work while sitting for 30 minutes at work can reduce musculoskeletal discomfort and lower back pain.

These researches suggest that there appears to be a significant benefit of breaking up prolonged sitting, the question of how often and how long a change in position needs to occur to achieve health benefits is still lack of concrete recommendations.

So in this case, two duty cycle had been defined as Table 8& Table 9. The cycle 1 is the short dwell cycle and the cycle 2 is the longer dwell time cycle. Each round of duty cycle 1 takes 22 minutes includes 20 minutes of no action time and 2 minutes of action time. This duty cycle follows the pattern used by Dunkstan. And the duty cycle 2 used a long dwell cycle which can be used as a compare group.

Table 8 Duty cycle #1 short dwell time

No action	Active time		
	Bladder1	Bladder2	Bladder3
20min	inflate	inflate	inflate
	dwell 10s	dwell 10s	dwell 10s
	deflate	deflate	deflate
	no action 10s	no action 10s	no action 10s

Table 9 - Duty cycle #2 long dwell time

No action	Active time		No action	Active time		No action	Active time	
	Bladder1			Bladder2			Bladder3	
10min	inflate		10min	inflate		10min	inflate	
	dwell	2min		dwell	2min		dwell	2min
	deflate			deflate			deflate	

4.8 Final Prototyping

Follow the exploration of the overall form, pneumatic system, bladder design and fabricating and bladder layout, the design prototype of the system integration was built. The complete bill of materials of the prototype and prototype exploded view can be found in Appendix E.

CHAPTER 5. IMPLEMENTATION

5.1 Human Subject Testing Protocol

In order to evaluate the perturbation system's ability to encourage postural shifts, a study was conducted to collect both qualitative and quantitative data. Specific aims of this study include gaining users' feedback on the prototype, quantifying data and generalizing results from the subjects and providing insights for further design refinement.

The study recruited eight subjects. Before the testing was conducted, participants were given an introduction of the prototype and the process. The study took place at Georgia Institute of Technology REAR Lab. The facility used in this study includes a workstation and the cushion prototype fabricated in the last section. This testing used an accelerometer and a seat pressure sensor to collect data. The accelerometer was placed on the sacrum of the subjects. The seat pressure sensor was placed beneath the prototype cushion on the office chair.

Before the testing began, all the subjects were asked to self-report their personal information included age group, gender, height, weight, daily sitting time and former condition. The questionnaire can be found in Appendix F.

This testing included three sections. Each section lasted for two hours and was deployed on different days. In the first section, subjects were asked to put on the accelerometer then sit on the office chair. They were required to adjust the chair to their comfort level. The cushion's bladder was not activated in this section. Seat sensor and accelerometer were activated and collected data. In two hours sitting time, subjects were required to work as usual. During the testing, subjects were allowed to take breaks any time they wanted. The time they left the seat was documented by the pressure sensor. After the test was done, subjects were asked to evaluate their sitting experience.

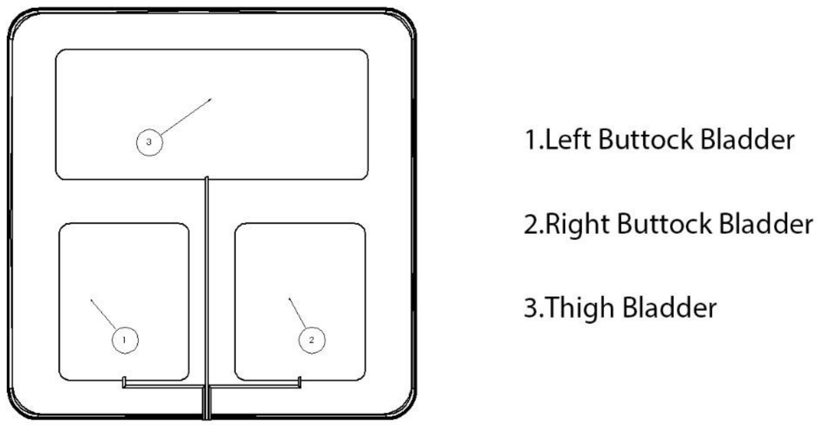


Figure 34 - Bladder layout for Testing

At the ending of this section, subjects were asked to evaluate their sitting experience as well. The second section was almost the same except that the prototype ran one of the duty cycle. The last section was almost the same as the second one. The prototype ran the remaining duty cycle. At the ending of this section, subjects were asked to evaluate their sitting experience.

5.2 Result

There was a total of eight participants (6 males and 2 females) for this study. And all their age group is in 20-29. Their average daily sitting time is 7.5 hours range from 5 to 10 hours every workday. Two subjects (subject 01 & subject 05) claimed they have former pain condition which is the lower back pain. And they still suffering from this pain. Subject #4 reported that she has former knee pain but not currently suffered. Table 11 shows the self-report information.

Table 10 - self-report information from testing subjects

	subject01	subject02	subject03	subject04	subject05	subject06	subject07	subject08
gender	M	F	M	F	M	M	M	M
height(cm)	173	170	178	170	182.8	180	188	188
weight(kg)	70	54.4	86.2	56.7	95.3	90.7	90.7	68
Sit time(hr)	8	7	8	10	8	9	5	5
Pain condition	LBP	/	/	Knee Pain	LBP	/	/	/
Still suffer(Y/N)	Y	N	N	N	Y	N	N	N

5.2.1 General Observation

After testing had concluded, the observations made and comments received from discussions showed some correlation among the subjects. Some general comments received from discussion with the test subjects are as follows:

1. Even though subjects were allowed to take a break anytime they wanted, the 2-hour sitting test might be too long for testing which may cause fatigue.
   Subject 03 stated after first sitting section," *The sitting itself doesn't make me feel uncomfortable, but I'm just not get used to sit that long.*"

2. The accelerometer used in the testing might cause somewhat uncomfortable.
   Based on observation, the subject who used to sit very deep and lean most parts of their back on the chair rest didn't perform that behavior that much. The reason might be the accelerometer on the sacrum.
   Subject 02 stated," *the band used to fix accelerometer to its position keeps remind me being tested.*"

3. The sound and vibration caused by the pump may has some effect on the result. And it's mentioned by several subjects.
   Subject 04 stated," *when the pump start working, I thought that was my mobile at first.*"

4. Subject 04 mentioned that it would be better if the bladder inflation is based on where you sit. No further detail is given here. Guess could be the place you sit, or most of your weight lay on.

5. Three subjects said they prefer duty cycle 2 better than duty cycle 1 for the following reasons:
   Subject 02 commented*," Love the 2nd cycle because it helped me to change position steadily, regularly. The 1st cycle was not comfortable for me because when I change my position at the first inflation, the 2nd and 3rd inflation follows, which is disrupting and "useless" for me.*
   Subject 03 commented*," I like duty cycle 2 better* -*duty cycle 1 is spread of shifts wasn't as effective.*"
   Subject 05 stated," *all of them (inflation of duty cycle 1) come at once. That's just too rush.*"

6. Other unexpected effect appeared when the test is conducted.
   Subject 03 stated*," Not really in any meaningful way though. After a certain point I was looking forward to the bladders activation/ deactivating.*" – write under Q10

7. Most of the subjects asked the remaining time of sitting during the test.

Results collected from the questionnaire is attached in Appendix G. Based on the overall conclusion of subjects' opinion on the cushion prototype, score of each prototype is calculated. Score 5 means "very comfortable, very uninterrupted, very helpful" and score 1 means "very uncomfortable, largely interrupted, very helpless".

The average comfort level of normal sitting without duty cycle is 3.75 and the average comfort level of duty cycle #1 is 4. The average comfort level of duty cycle #2 is 4.25. The average interruptive level of duty cycle #1 is 3.875 and duty cycle #2's is 4.25. The average helpful level of duty cycle #1 is 3.875 and duty cycle #2's is 4.5.

5.2.2 Empirical Results

To further evaluate the sitting experience of the subjects and the effectiveness of the prototype, the data collected by the accelerometer and the pressure sensor is analyzed. Table 11 shows the summary of the shifts performed by eight subjects under three conditions.

Table 11 - Summary of the shifts performed by eight subjects

	subject#1			subject#2			subject#3			subject#4		
duty cycle	none	#1	#2	none	#1	#2	none	#1	#2	none	#1	#2
sagittal_shift	68	83	76	56	47	33	47	16	44	54	56	44
coronal_shift	55	68	68	6	21	11	40	17	13	44	34	34
sit_time (exclude_standing)	101	100	106	101	109	118	101	93	96	90	102	106
sagittal_shift/ hr	40.39604	49.8	43.01887	33.26733	25.87156	16.77966	27.92079	10.32258	27.5	36	32.941176	24.90566
coronal_shift/ hr	32.67327	40.8	38.49057	3.564356	11.55963	5.59322	23.76238	10.96774	8.125	29.33333	20	19.24528
	subject#5			subject#6			subject#7			subject#8		
duty cycle	none	#1	#2	none	#1	#2	none	#1	#2	none	#1	#2
sagittal_shift	27	44	13	34	22	29	34	18	25	28	52	54
coronal_shift	18	41	27	8	8	7	13	11	10	19	56	49
sit_time (exclude_standing)	92	102	91	115	110	115	114	115	113	110	113	98
sagittal_shift/ hr	17.6087	25.88235	8.571429	17.73913	12	15.13043	17.89474	9.391304	13.27434	15.27273	27.610619	33.06122
coronal_shift/ hr	11.73913	24.11765	17.8022	4.173913	4.363636	3.652174	6.842105	5.73913	5.309735	10.36364	29.734513	30

All the data collected by the accelerometer and pressure sensor were analyzed and plot as graphs. The full data graphs can be found in Appendix H. Figure 36 shows an example of the plot layout of the sitting experience based on the collected data. Each test takes 2 hours and the testing time may slightly vary due to subjects' occupancy. For the consistency of data and reduce the effect of the testing method, the first and last 7 minutes of data are trim off.

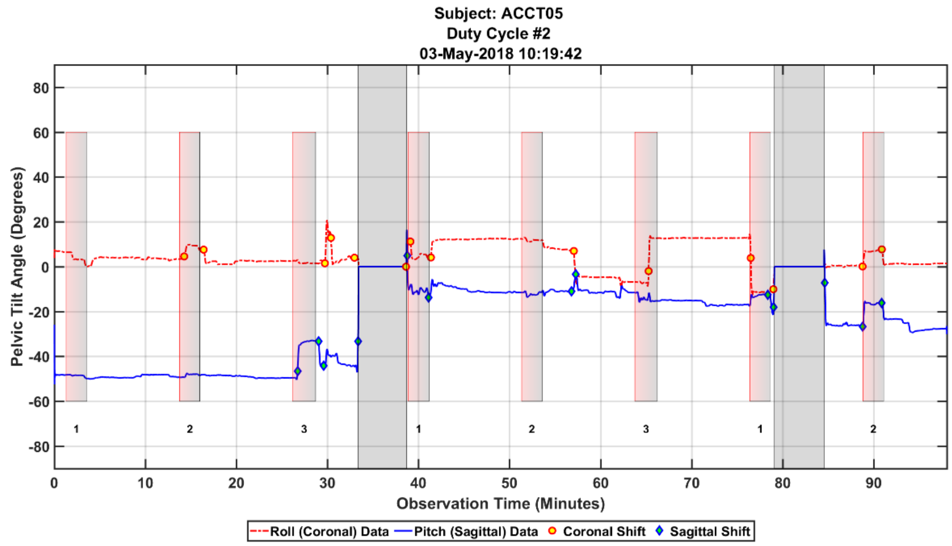


Figure 35 - An example of a typical sitting behavior

Each grey box shows the time when the subject is not in the seat. The gradient boxes indicate the time when the bladder is activated. The number under the gradient box shows which bladder is activated. The red side of the gradient box indicates the start of bladder inflating. Normally this period lasts for about ten seconds when the bladder reaches the setting pressure. The bladder keeps in this condition until it deflates itself which is indicated by the black line of the gradient box.

All the postural changes are indicated on the figures as the small circles. The shifts are calculated based on the Dunk's paper (Dunk & Callaghan, 2010). Figure 37 shows an example of the shift pattern which indicates how a shift is counted.

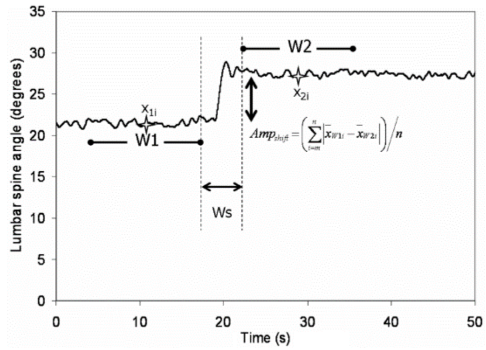


Figure 36 - An example of the shift pattern and the parameters used in the recognition algorithm

The average values were computed on a point-by-point basis for two 15-second moving windows (W1 and W2), each centered on a point (x1i and x2i) and separated by Ws (15 seconds). Any two consecutive windows being offset by a change greater than 5 degrees were classified as a sagittal shift. Any two consecutive windows being offset by a change greater than 3.5 degrees were classified as a coronal shift. Because Dunk's paper put the accelerometer on the chest while this study put the sensor on the sacrum. In the pilot study, researchers found that the maximum extension angle of the chest tilt range from 60 to -30 degree in the sagittal plane and 30 to -30 degree in the coronal plane. The maximum extension angle of the chest tilt range from 70 to -15 degree in the sagittal plane and 20 to -20 degree in the coronal plane. The parameter which defines the shift angle is modified based on this pilot study.

5.3 Overall Conclusion

Almost all the subjects performed more sagittal shifts than coronal shifts. Subject #1 and subject #4 behaved a very active sitting style. They shift their postures almost less than every 5 minutes. They behaved actively during all three trials and their sitting behaviors did not change much whether the bladders were activated or not. They have a higher shift frequency than the bladder duty cycle which might be the reason why prototype doesn’t have much effect on them.

Subject #2 has a lot of sagittal moves and a little coronal move. The coronal shifts increased when the bladders were activated. However, the shifts didn’t seem related to the duty cycle and the shift degree is relatively low.

Subject #3 mentioned his not getting used to sitting that long during the first sitting section. However, he still considered the sitting comfort level neutral. He performed far more movement in the first section than the other two section which he considers somewhat comfortable. His reaction to the bladder inflation is not obvious during the first duty cycle. He thought duty cycle #1 was somewhat helpless in helping shift posture. Subject #3 seems reacted to the bladder in duty cycle 2. Even though the movement is not large enough to be considered as a posture shift in some cases. The deflation of the bladder seems to have more effect than the inflation of the bladder to subject #3.

The duty cycle#2 seems like have an influence on subject #5. Subject’s pelvic tilt to the left when the right thigh bladder inflates and it returned to upright when the bladder deflates. Some relations can be seen from the figure.

Subject #6 didn’t seem to change his sitting pattern in three sections. The duty cycle 1 seems have not influence on him. Duty cycle 2 helps him break up prolonged sitting several times, especially the left thigh bladder’s deflation. Subject #7’s condition is similar to subject #7, duty cycle 1 seems has no effect. Duty cycle #2 helps break up prolonged sitting and this subject performs a sagittal shift. Subject #8 become very active when the bladder is activated.

Table: Summary of the relationship between shifts and inflation in the Appendix H shows the detail information of the shifts occurred during the inflation. All the shifts occurred during the inflation were showed on the table.

Based on the layout result of the posture shift, in duty cycle 1, subjects shift their body 67% time when the bladder is activated. And subjects shift their body 82% time when the bladder is activated in duty cycle 2. Since duty cycle 2 received both better user feedback and better results in promoting active sitting. Duty cycle 2 is picked here as the final design choice.

5.4 Design modification and Reasoning

The design modification was made based on user feedback and researchers' observation. During the testing process, researchers found that it's hard to tell the difference between front side and back side of the cushion, which causes inconvenience. Since the polymer cover should be placed on the bladder to reduce the intrusive. One solution to this problem was adding a logo on the front side (Figure 38).

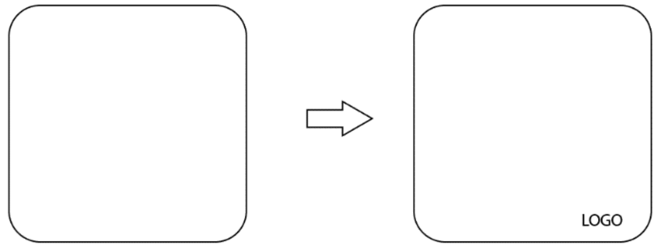


Figure 37 - Adding a logo on the front side of the cushion

The current prototype has a large control box hung on the back of the seat. It both creates inconvenience and waste the space. The air pipe used in the prototype is also unnecessary. To improve the design, new components should be chosen to reduce the size. The controller and the box can be redesigned to be compact. The pipe length can be reduced by attaching the box directly beside the cushion (Figure 39).

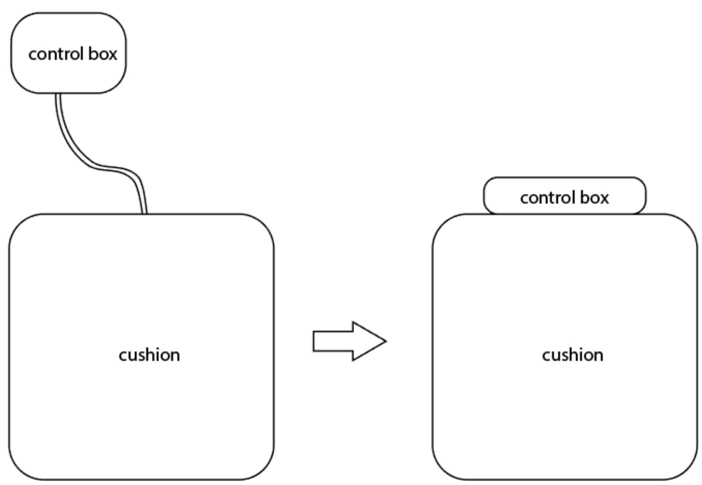


Figure 38 - Repositioning the control box

According to the user feedback, the pump's noise and vibration somewhat cause disturb. To minimize disturb, the first method is adding noise cancellation. A foam wrap around the motor is a quick way which can reach a good result in a low expense way (Figure40). Based on the previous study, the current pump's power exceeds the maximum of the requirement. Using a smaller pump not only can save the cost and energy but also can reduce the noise (Figure 41). The minimum requirement of the pump pressure is 117k Pa which can be achieved by most of the model on the market.

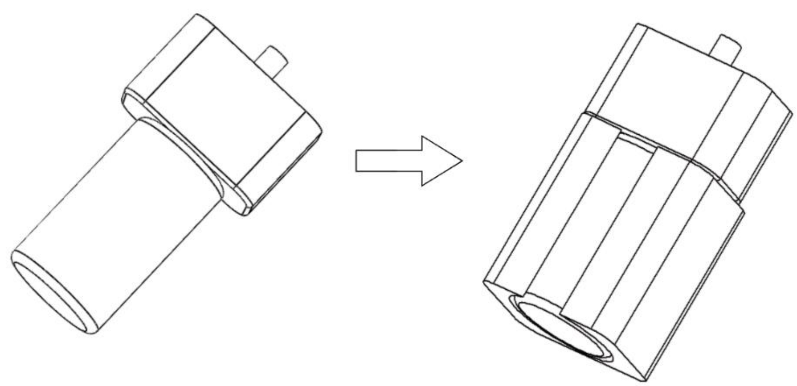


Figure 39 - Using foam to reduce the noise and vibration

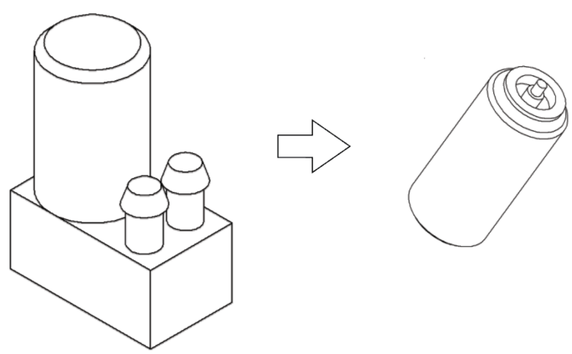


Figure 40 - Choosing a smaller pump

CHAPTER 6. FINAL DESIGN AND DISCUSSION

6.1 Final Design

The design received positive feedback from the potential users, and the effectiveness of this design was recognized. The creativity of the product, to promote the active seating through passive perturbation was evaluated as effective and comfortable.

Compared with the existing products in the market, the design filled the white space in providing an adaptable device which can promote the active seating and improve the ergonomics of workplace sitting.

The material cost for the cushion was estimated at $160 for the mass production. The price is acceptable when it’s compared to its potential competitors. After optimization, the final design is shown in Figure 42. The detailed rendering and assembly are shown in Appendix I and Appendix J.

Figure 41 - Final design of the cushion

Figure 42 - Final design detailed dimension

6.2 Limitation

While the research methodology used in this thesis proved to be fruitful, there were some improvements that could be have been made. For the survey concerning on which bladder configurations office workers prefer, subjects are asked to use and sit on the bladders without running any duty cycle and only inflates bladder for two times. The sitting experience is different from prolonged sitting which may cause different opinion. However, due to the time limitation and cost-effective, the testing is conducted this way.

Secondly, due to the limited user testing time, the user testing did not simulate the real use case. The participants only sit for 2 hours on the prototype, which was different in the practical situation that the user might stay sitting for the whole day. Further user testing needs to be dome for long-term use.

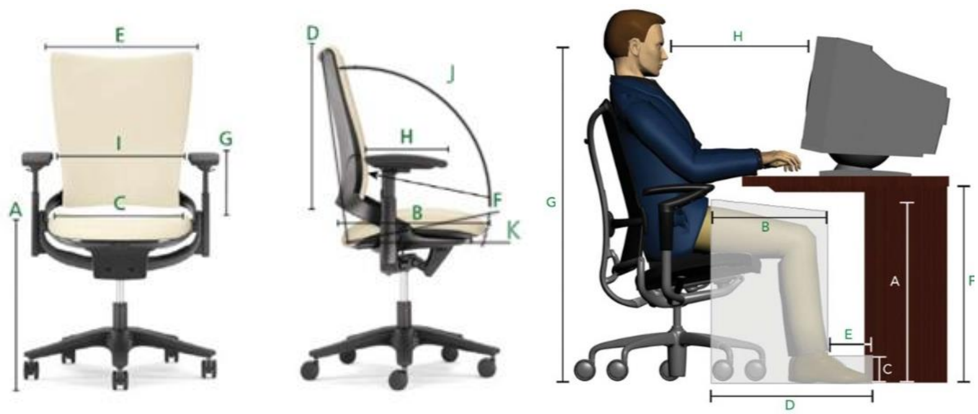
During the final prototype user testing, the users were asked to adjust their office chair to the comfort level every time before the testing begins. Hence the chair condition would be slightly different each time. And the using of the accelerometer can cause discomfort.

Due to the limitation of prototyping technique, the inflation of the bladder is not continuously. In mass production, this problem can be solved with a more professional method.

6.3 Future Works

This project focus on improving the office worker's sitting ergonomics and promoting the active sitting of sedentary workers. Future work should conduct more prototype testing for the comfortability as well as long-term use by the potential user. The use case of this design should not be limited to only office workers. All the people who have prolonged sitting such as truck drivers, students, and wheelchair users can be the target user of this product. So there is an opportunity to develop the product in a more specific use case.

APPENDIX A. CHAIR MEASUREMENT STANDARD



A: seat height

B: seat Depth

C: seat width

D: backrest height

E: backrest width

G: armrest height

H: armrest length

I: distance between arm length

J: seat-to-back angle

K: seat- angle

A: the height of the desk (wrist height)

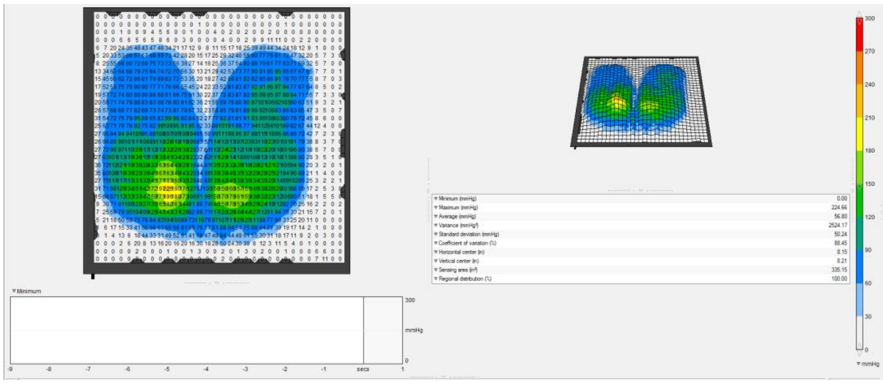
B: depth of the knee

G: Eye height

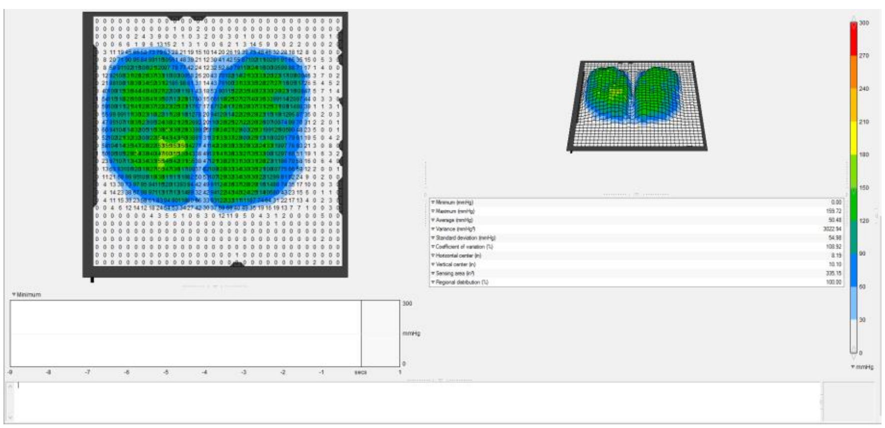
H: view depth

F: object height (monitor)

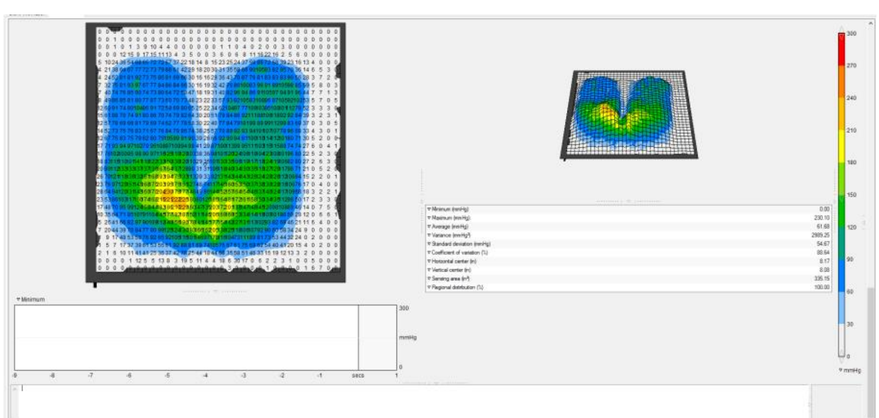
APPENDIX B. PRESSURE DISTRIBUTION OF DIFFERENT POSTURES



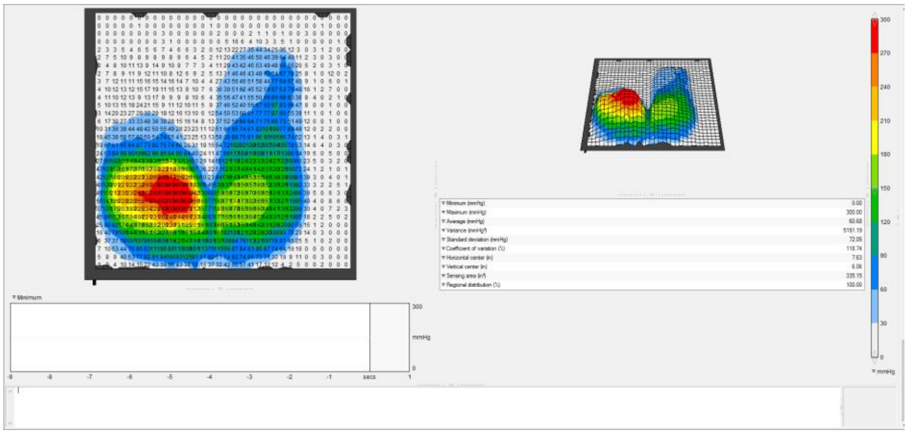
Posture 1: upright



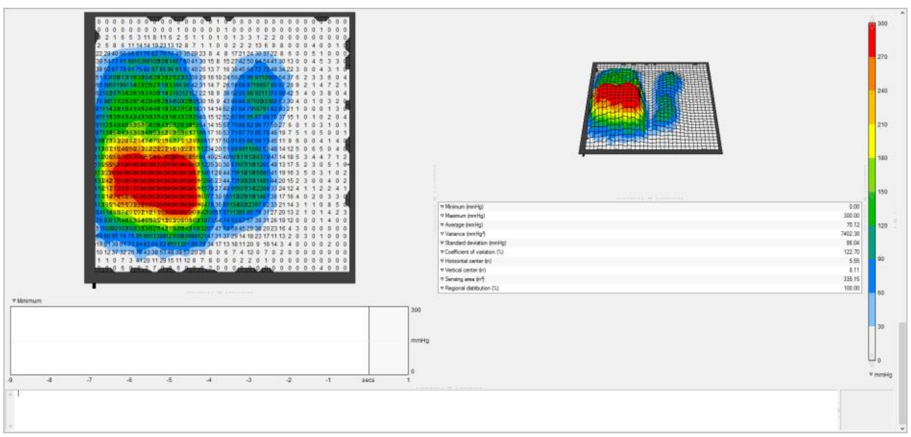
Posture 2: Lean front



Posture 3: lean back

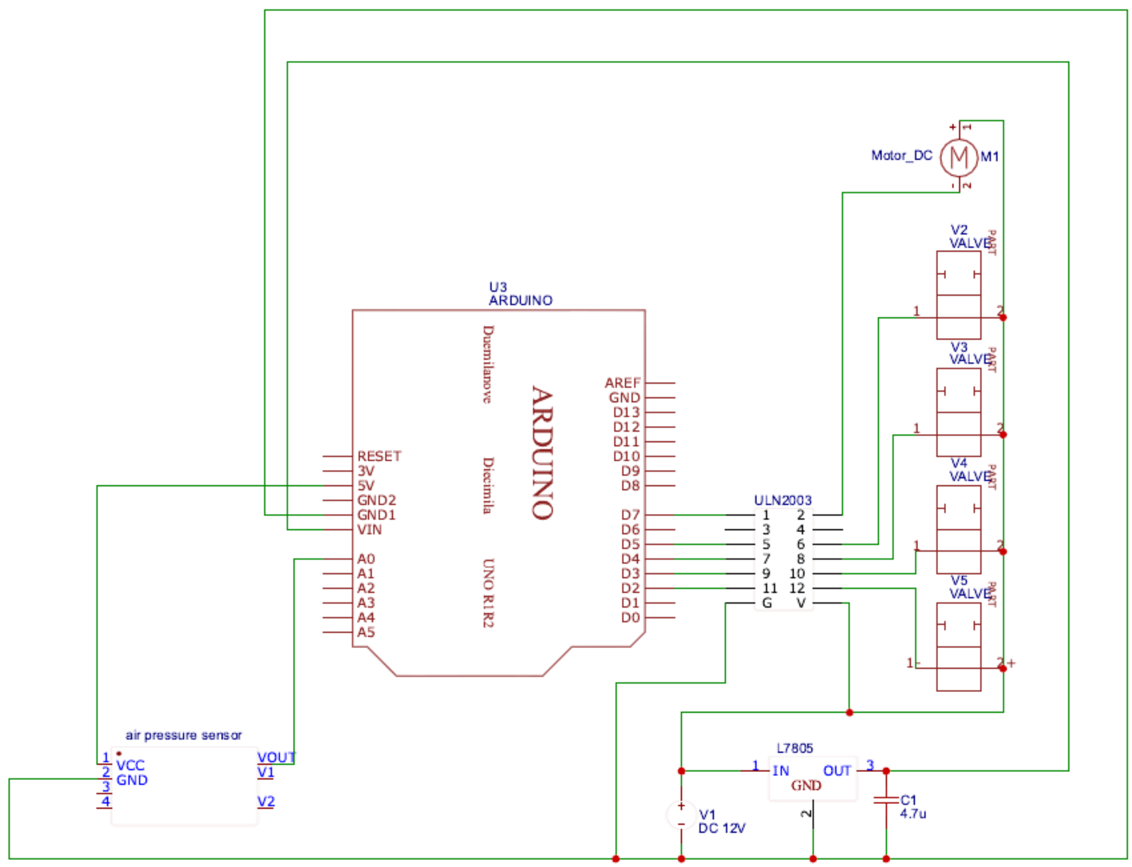


Posture 4 :leg cross



Posture 5: Lean side

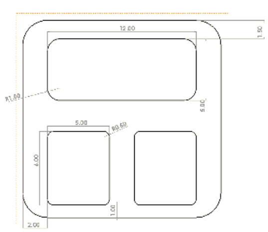
APPENDIX C. CIRCUIT DIAGRAM OF THE PROTOTYPE



Part name	Brand	Number
Micro Control Board	Arduino Uno U3	1
Air Pressure Sensor	NXP Semiconductors EAR99	1
Solenoid Valve	MUMA Tech 12V	4
Transistors	ULN2003	1
Voltage Regulator	L7805	1
Capacity	4.7u	1

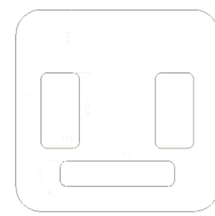
APPENDIX D. ACTIVE SEAT PROTOTYPE FOR SEDENTARY OFFICE WORKERS

In this section you will be asked to rate the comfort level of 3 configurations of bladder design.



A

B



C

1) Rate the comfort level of Design A.

Very comfortable Somewhat comfortable Neutral Somewhat uncomfortable Very uncomfortable

2) Rate the comfort level of Design B.

Very comfortable Somewhat comfortable Neutral Somewhat uncomfortable Very uncomfortable

3) Rate the comfort level of Design C.

Very comfortable Somewhat comfortable Neutral Somewhat uncomfortable Very uncomfortable

---

4) Rate the effort of using the foam cushion. (Putting the cushion on the chair)

Convenient Somewhat convenient Inconvenient Very inconvenient

5) Do you feel uncomfortable when sitting on the foam cushion?

Very comfortable Somewhat comfortable Neutral Somewhat uncomfortable Very uncomfortable

6) Do you feel your weight shift when the bladder is inflating? (Foam)

Large shift Small shift None shift

7) Rate the effort of using the polymer cushion. (Putting the cushion on the chair)

Convenient Somewhat convenient Inconvenient Very inconvenient

8) Do you feel uncomfortable when sitting on the polymer cushion?

Very comfortable Somewhat comfortable Neutral Somewhat uncomfortable Very uncomfortable

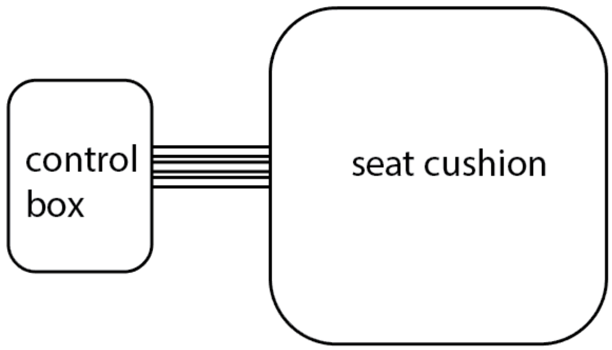
9) Do you feel your weight shift when the bladder is inflating? (Polymer)

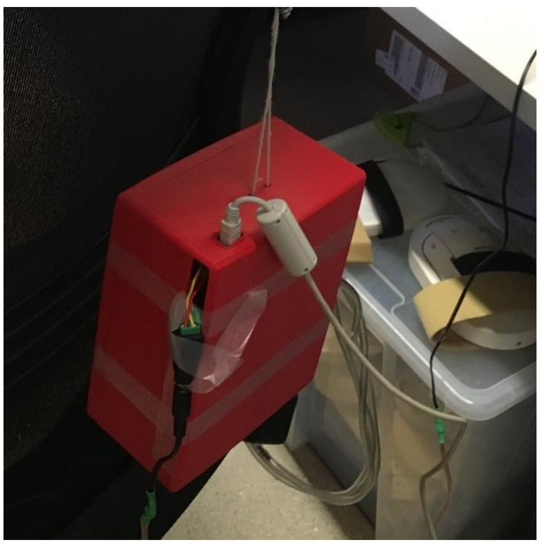
Large shift Small shift None shift

10) Do you have any additional questions or comments on either prototype?

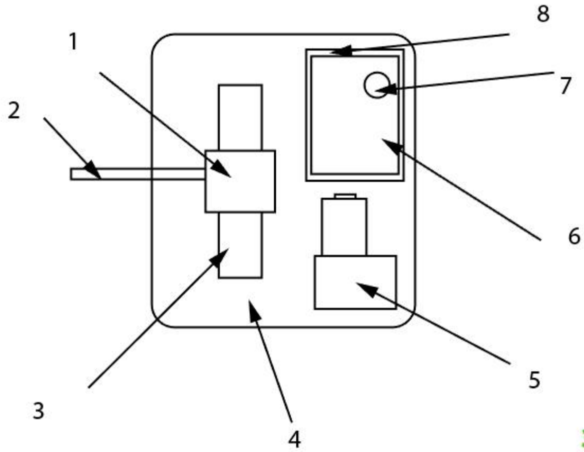
APPENDIX E. FINAL PROTOTYPING

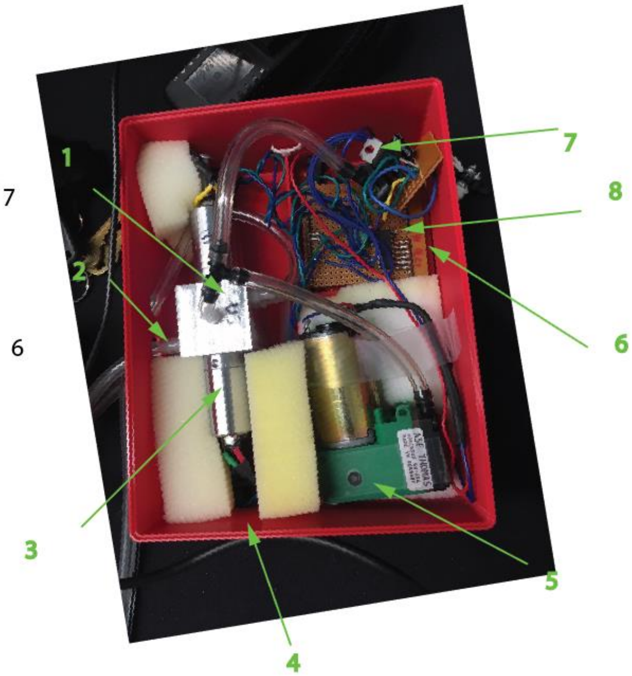
The prototype of active cushion includes two parts, which are the controller part and the cushion part. Two parts were connected by PVC air tube.





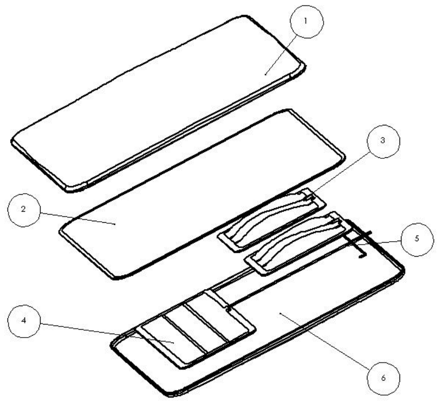
Control Box of the prototype (left) **Seat cushion (right)**

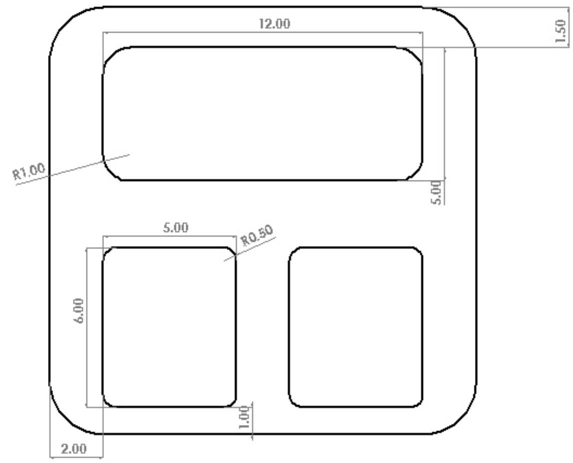




Bill of material

No.	name	material
1	manifold	aluminum
2	airfitting(out)	¼ in
3	solenoid valve	MUMA Tech 12V
4	control Box	3d print (PLA)
5	Air pump(12V)	ASF THOMAS
6	PCB shield	Appendix c
7	air pressure sensor	MPX4250AP CASE 867B-04
8	Arduino red board	





PART NO.	NAME	MATERIAL
1	Top Fabric Cover	space foam
2	Cushion base	polymer
3	bladder Port	PVC
4	Pneumatic connectior	PVC
5	Customized bladder	TPU
6	Bottom Fabric Cover	space foam

APPENDIX F. ACTIVE SEAT PROTOTYPE FOR SEDENTARY OFFICE WORKERS (2 HOURS TEST)

Section 1: personal information

1. In what age group are you?
   - ◯ 19 and under
   - ◯ 20-29
   - ◯ 30-39
   - ◯ 40-49
   - ◯ 50-59
   - ◯ 60+

2. Gender
   - ◯ Male
   - ◯ Female

3. Your height ______

4. Your Weight______

5. How long do you sit on chair every day?

   ____

6. Do you have former pain condition? (Lower back pain, back and spine injuries…)

   ____

7. Are you still suffering from this pain? (Y/N)

   ____

Section 2: Normal sitting

8. Do you feel uncomfortable after sitting on the prototype for two hours?

○ Very comfortable ○ Somewhat comfortable ○ Neutral ○ Somewhat uncomfortable ○ Very uncomfortable

Section 3: Opinions on the prototype (duty cycle 1)

9. Do you feel comfortable after sitting on the prototype for two hours?

○ Very comfortable ○ Somewhat comfortable ○ Neutral ○ Somewhat uncomfortable ○ Very uncomfortable

10. Do you think your work was interrupted by the prototype?

○ Very uninterrupted ○ Somewhat uninterrupted ○ Neutral ○ Somewhat interrupted ○ Largely interrupted

11. Do you think the prototype helps you shift position?

○ Very helpful ○ Somewhat helpful ○ Neutral ○ Somewhat helpless ○ Very helpless

Section 4: Opinions on the prototype (duty cycle 2)

12. Do you feel comfortable after sitting on the prototype for two hours?

○ Very comfortable ○ Somewhat comfortable ○ Neutral ○ Somewhat uncomfortable ○ Very uncomfortable

13. Do you think your work was interrupted by the prototype?

○ Very uninterrupted ○ Somewhat uninterrupted ○ Neutral ○ Somewhat interrupted ○ Largely interrupted

14. Do you think the prototype helps you shift position?

○ Very helpful ○ Somewhat helpful ○ Neutral ○ Somewhat helpless ○ Very helpless

Do you have any additional questions or comments on both prototypes?

APPENDIX G. QUESTIONNAIRE RESULT OF THE TWO HOUR CUSHION TESTING

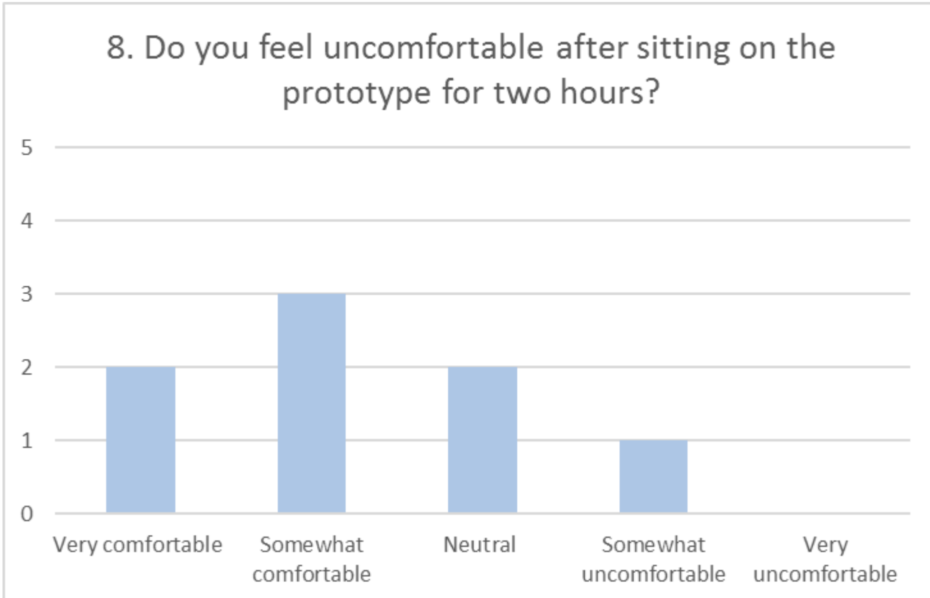


Figure: result for normal sitting comfort level

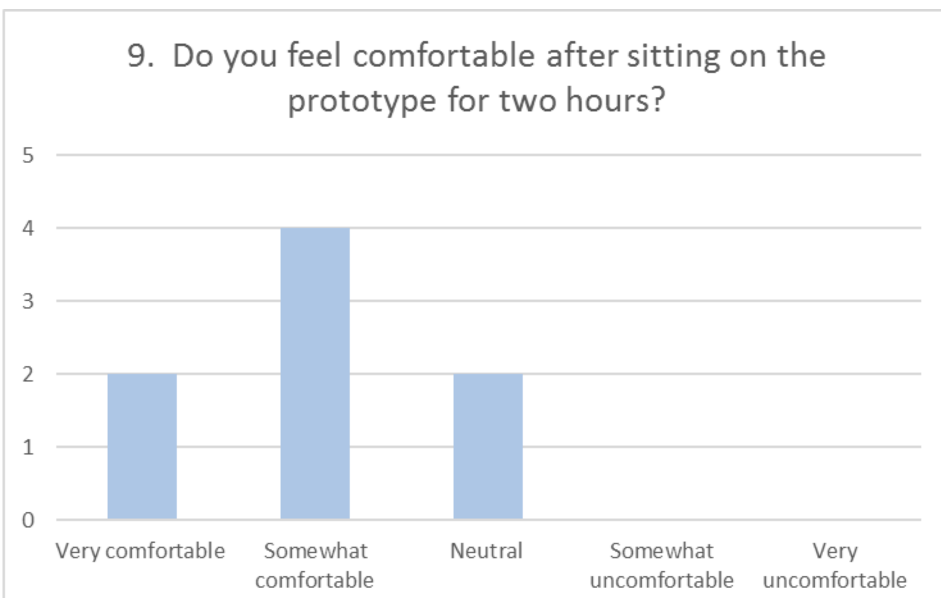


Figure: result for Duty cycle #1 comfort level

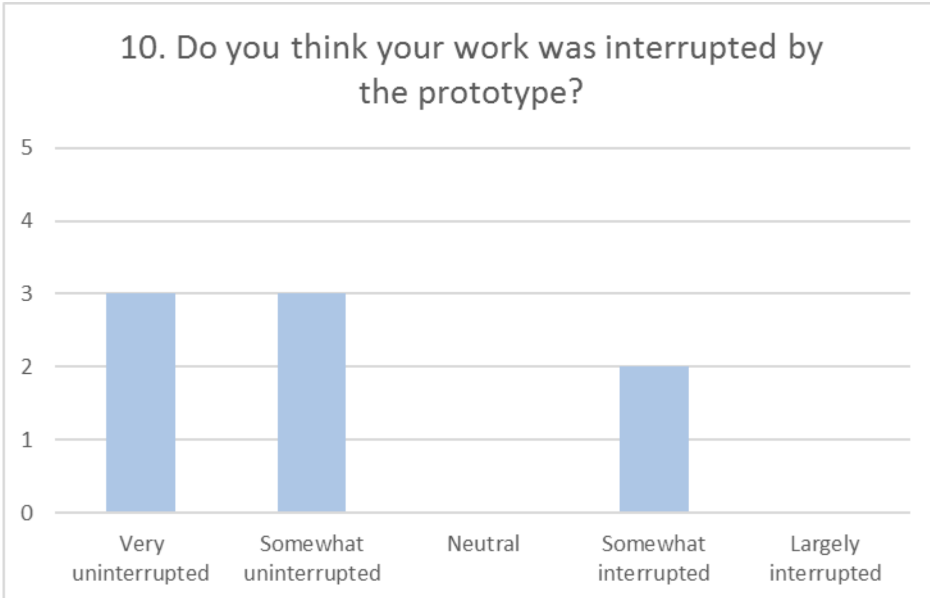


Figure: result for Duty cycle #1 interrupt level

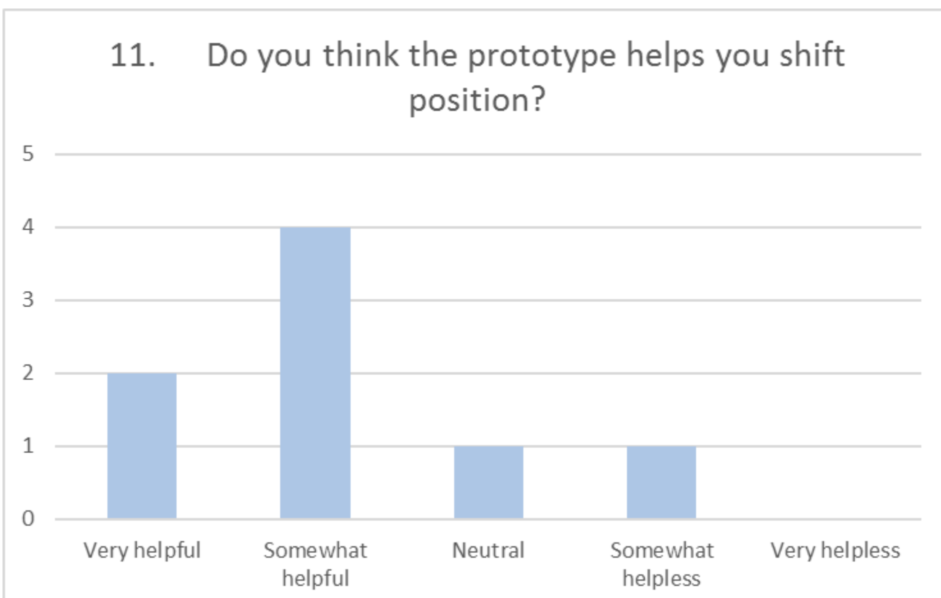


Figure: result for Duty cycle #1 helpful level

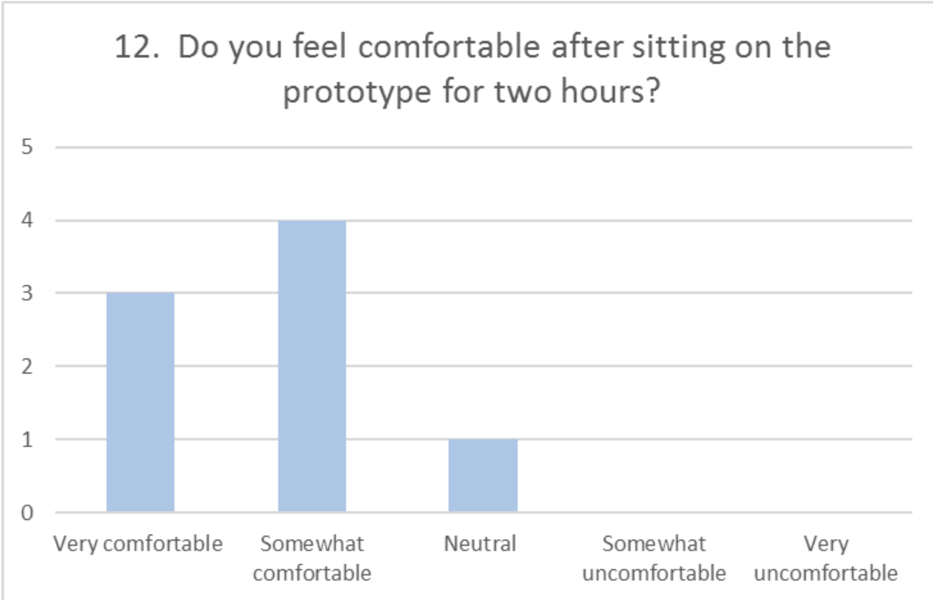


Figure: result for Duty cycle #2 comfort level

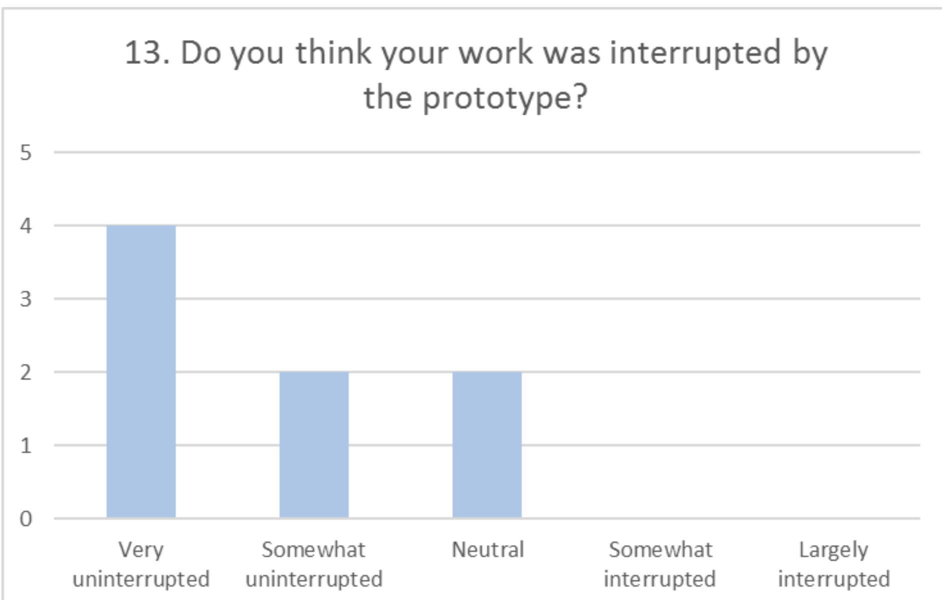


Figure: result for Duty cycle #2 interrupt level

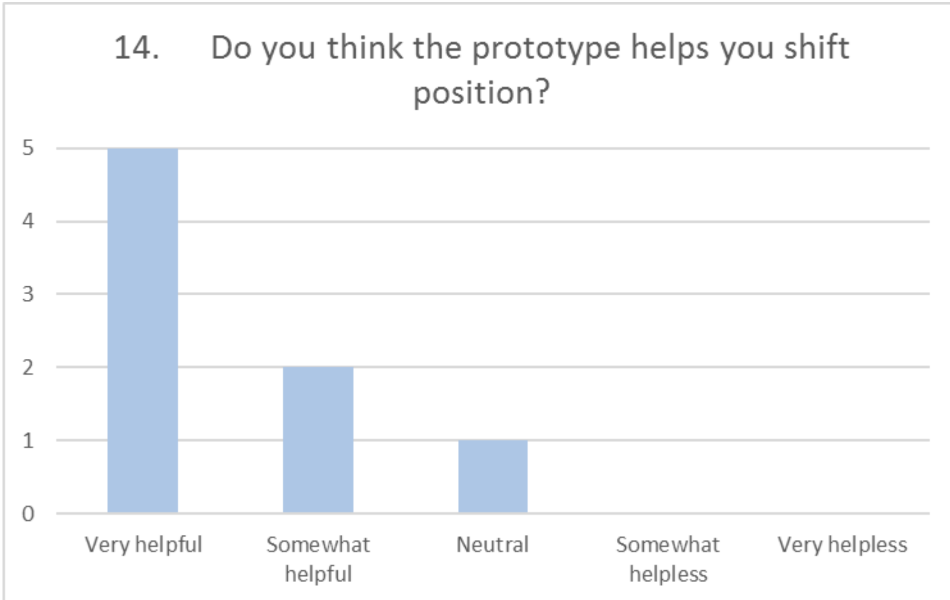


Figure: result for Duty cycle #2 helpful level

Summary data for the questionnaire

	Question 8	Question 9	Question10	Question11	Question12	Question13	Question14
sub#1	D	C	D	B	B	A	A
sub#2	C	C	D	B	C	B	A
sub#3	C	B	B	D	B	C	B
sub#4	A	A	A	B	B	C	A
sub#5	B	B	B	A	A	A	A
sub#6	B	B	A	C	A	A	C
sub#7	B	A	A	B	A	A	B
sub#8	A	B	B	A	B	B	A

	Question 8	Question 9	Question 10	Question 11	Question 12	Question 13	Question 14
sub#1	2	3	2	4	4	5	5
sub#2	3	3	2	4	3	4	5
sub#3	3	4	4	2	4	3	4
sub#4	5	5	5	4	4	3	5
sub#5	4	4	4	5	5	5	5
sub#6	4	4	5	3	5	5	3
sub#7	4	5	5	4	5	5	4
sub#8	5	4	4	5	4	4	5
Average	3.75	4	3.875	3.875	4.25	4.25	4.5

Score 5 means “very comfortable, very uninterrupted, very helpful” and score 1 means “very uncomfortable, largely interrupted, very helpless”.

The average comfort level of normal sitting without duty cycle is 3.75 and the average comfort level of duty cycle #1 is 4. The average comfort level of duty cycle #2 is 4.25. The average interruptive level of duty cycle #1 is 3.875 and duty cycle #2’s is 4.25. The average helpful level of duty cycle #1 is 3.875 and duty cycle #2’s is 4.5.

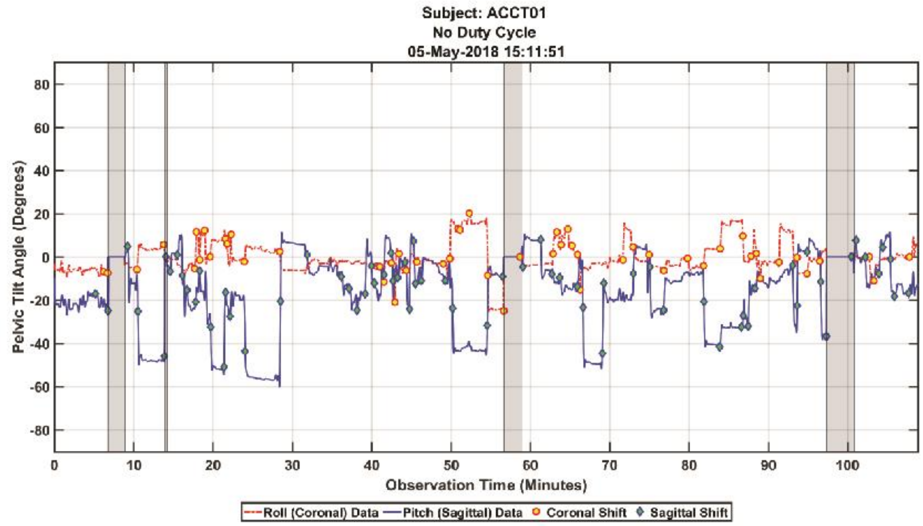
APPENDIX H. RESULT OF DATA COLLECTED WITH SENSORS

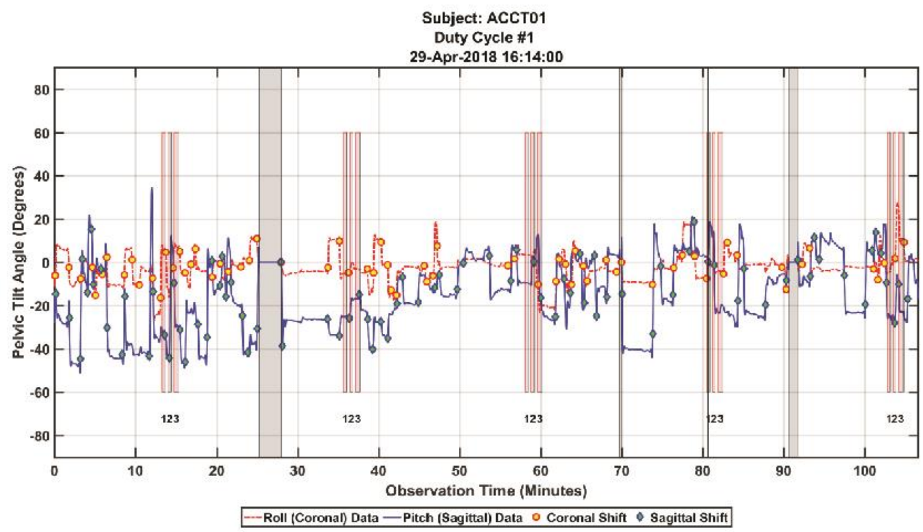
Each grey box shows the time when the subject is not in the seat. The gradient boxes indicate the time when the bladder is activated. The number under the gradient box shows which bladder is activated. The red side of the gradient box indicates the start of bladder inflating. Normally this period lasts for about ten seconds when the bladder reaches the setting pressure. The bladder keeps in this condition until it deflates itself which is indicated by the black line of the gradient box.

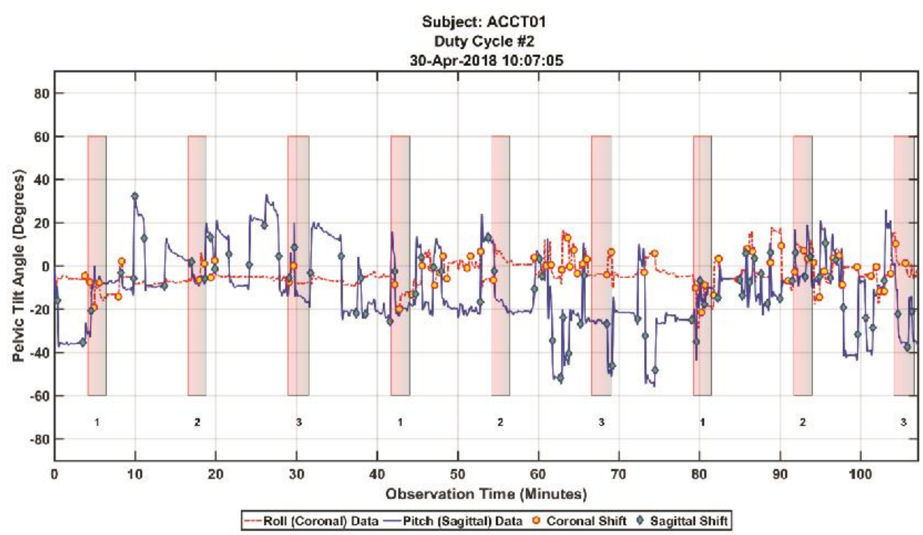
	subject#1			subject#2			subject#3			subject#4		
duty cycle	/	#1	#2	/	#1	#2	/	#1	#2	/	#1	#2
sagittal_shift	68	83	76	56	47	33	47	16	44	54	56	44
coronal_shift	55	68	68	6	21	11	40	17	13	44	34	34
sit_time (exclude_standing)	101	100	106	101	109	118	101	93	96	90	102	106
sagittal_shift/ hr	40.39604	49.8	43.01887	33.26733	25.87156	16.77966	27.92079	10.32258	27.5	36	32.941176	24.90566
coronal_shift/ hr	32.67327	40.8	38.49057	3.564356	11.55963	5.59322	23.76238	10.96774	8.125	29.33333	20	19.24528

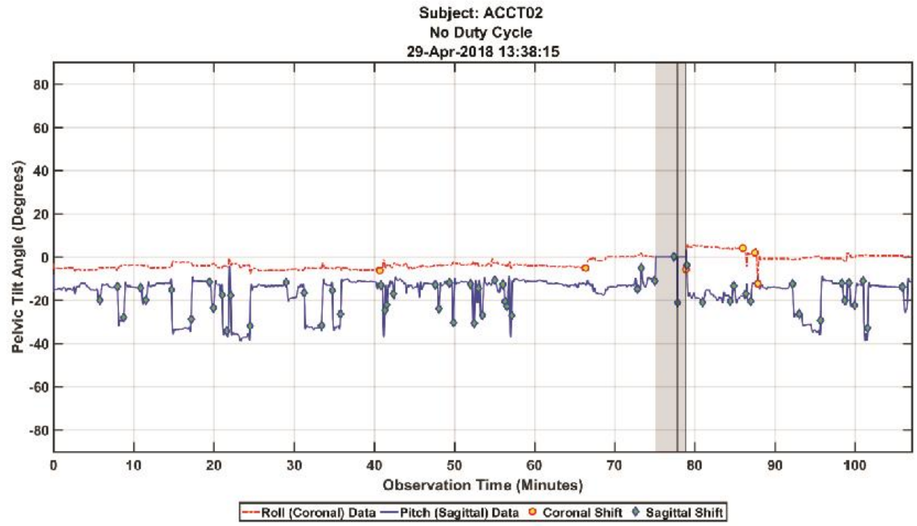
	subject#5			subject#6			subject#7			subject#8		
duty cycle	/	#1	#2	/	#1	#2	/	#1	#2	/	#1	#2
sagittal_shift	27	44	13	34	22	29	34	18	25	28	52	54
coronal_shift	18	41	27	8	8	7	13	11	10	19	56	49
sit_time (exclude_standing)	92	102	91	115	110	115	114	115	113	110	113	98
sagittal_shift/ hr	17.6087	25.88235	8.571429	17.73913	12	15.13043	17.89474	9.391304	13.27434	15.27273	27.610619	33.06122
coronal_shift/ hr	11.73913	24.11765	17.8022	4.173913	4.363636	3.652174	6.842105	5.73913	5.309735	10.36364	29.734513	30

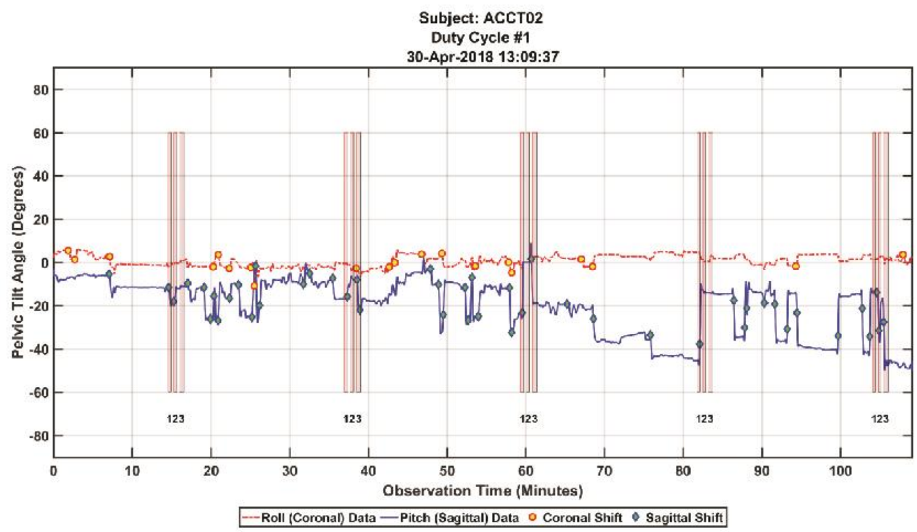
Table: Summary of the shifts performed by eight subjects

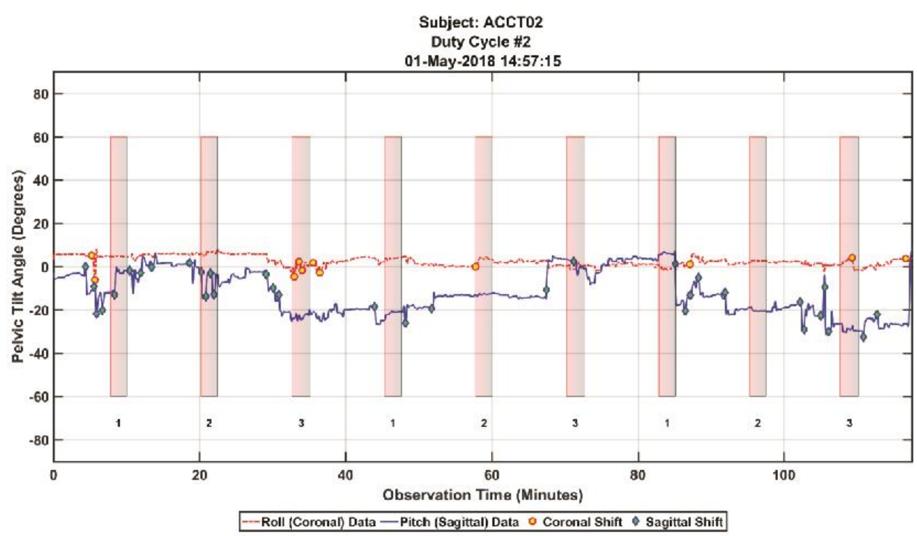

Subject: ACCT01
No Duty Cycle
05-May-2018 15:11:51
Pelvic Tilt Angle (Degrees)
Observation Time (Minutes)
Roll (Coronal) Data
Pitch (Sagittal) Data
Coronal Shift
Sagittal Shift

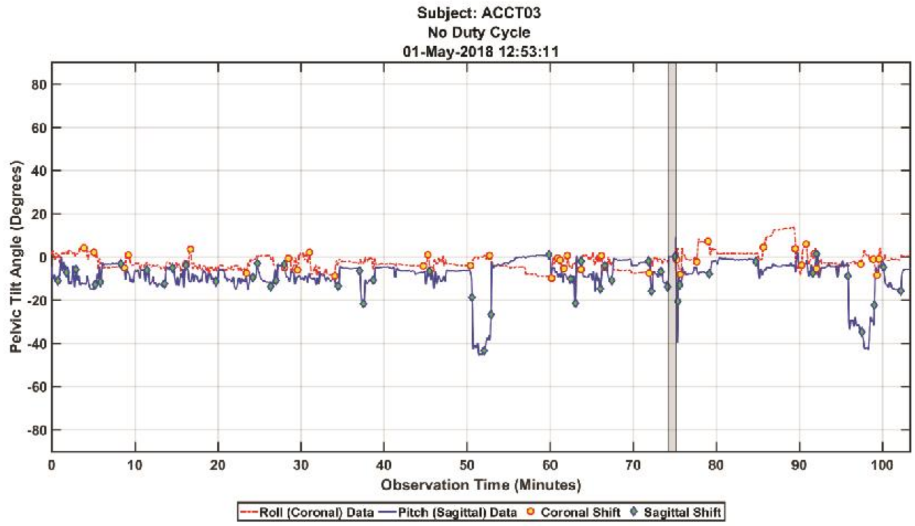

Subject: ACCT01
Duty Cycle #1
29-Apr-2018 16:14:00
Pelvic Tilt Angle (Degrees)
123
123
123
123
123
Observation Time (Minutes)
Roll (Coronal) Data
Pitch (Sagittal) Data
Coronal Shift
Sagittal Shift

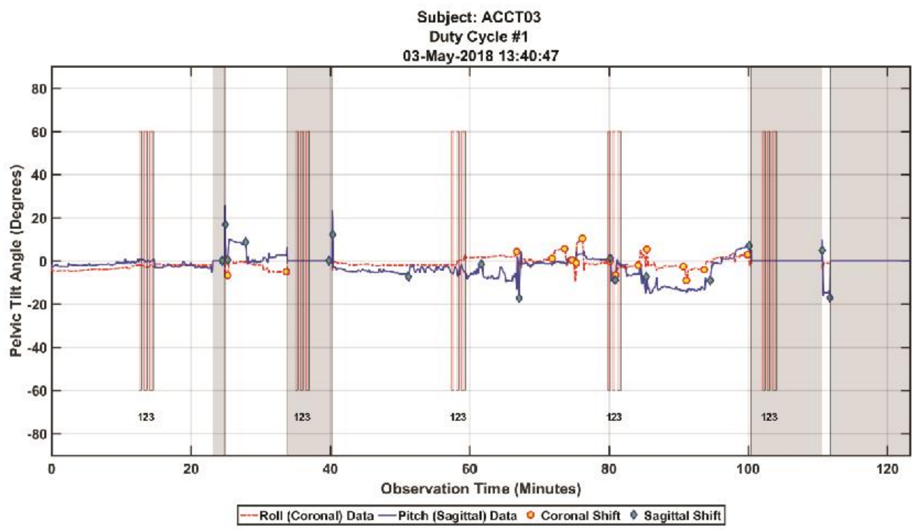

Subject: ACCT01
Duty Cycle #2
30-Apr-2018 10:07:05
Pelvic Tilt Angle (Degrees)
1
2
3
1
2
3
1
2
3
Observation Time (Minutes)
Roll (Coronal) Data
Pitch (Sagittal) Data
Coronal Shift
Sagittal Shift

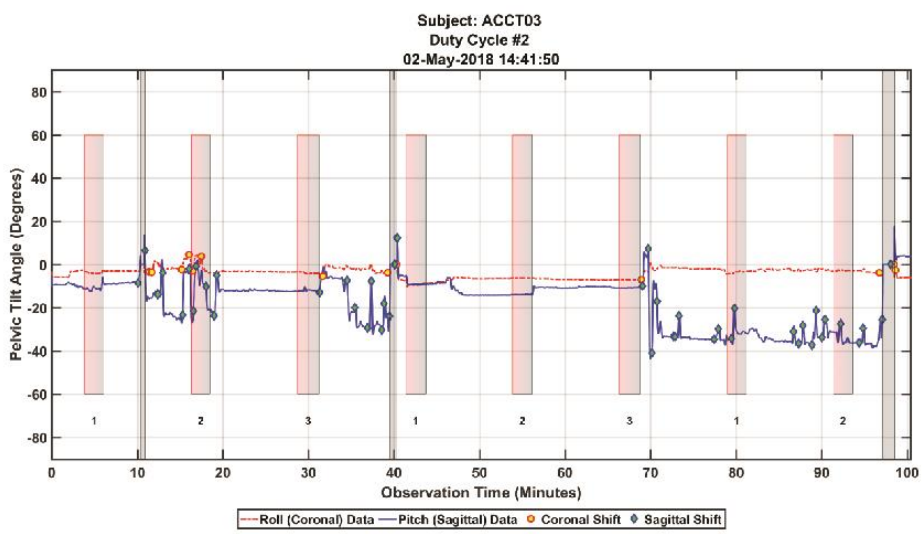

Subject: ACCT02
No Duty Cycle
29-Apr-2018 13:38:15
Pelvic Tilt Angle (Degrees)
Observation Time (Minutes)
Roll (Coronal) Data
Pitch (Sagittal) Data
Coronal Shift
Sagittal Shift


Subject: ACCT02
Duty Cycle #1
30-Apr-2018 13:09:37
Pelvic Tilt Angle (Degrees)
123
123
123
123
123
Observation Time (Minutes)
Roll (Coronal) Data
Pitch (Sagittal) Data
Coronal Shift
Sagittal Shift


Subject: ACCT02
Duty Cycle #2
01-May-2018 14:57:15
Pelvic Tilt Angle (Degrees)
1
2
3
1
2
3
1
2
3
Observation Time (Minutes)
Roll (Coronal) Data
Pitch (Sagittal) Data
Coronal Shift
Sagittal Shift


Subject: ACCT03
No Duty Cycle
01-May-2018 12:53:11
Pelvic Tilt Angle (Degrees)
Observation Time (Minutes)
Roll (Coronal) Data
Pitch (Sagittal) Data
Coronal Shift
Sagittal Shift


Subject: ACCT03
Duty Cycle #1
03-May-2018 13:40:47
Pelvic Tilt Angle (Degrees)
123
Observation Time (Minutes)
Roll (Coronal) Data
Pitch (Sagittal) Data
Coronal Shift
Sagittal Shift


Subject: ACCT03
Duty Cycle #2
02-May-2018 14:41:50
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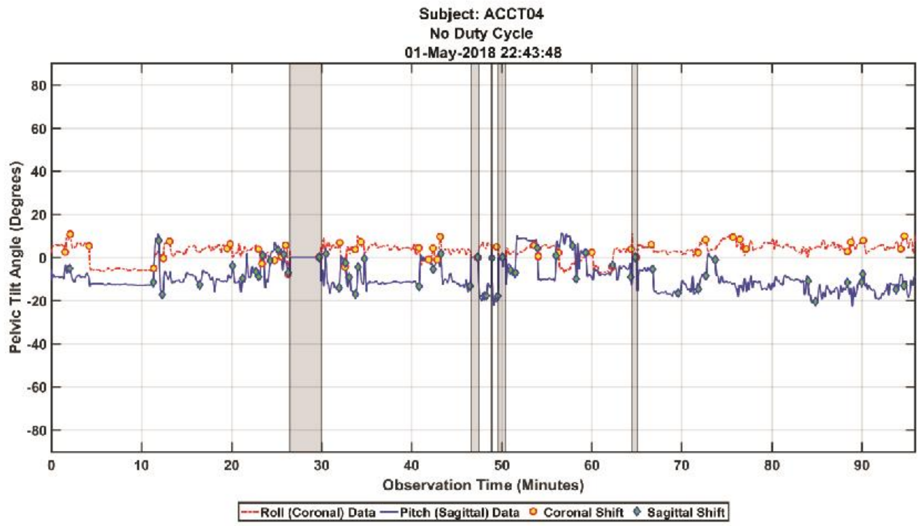
Observation Time (Minutes)
Roll (Coronal) Data
Pitch (Sagittal) Data
Coronal Shift
Sagittal Shift



Subject: ACCT04
No Duty Cycle
01-May-2018 22:43:48
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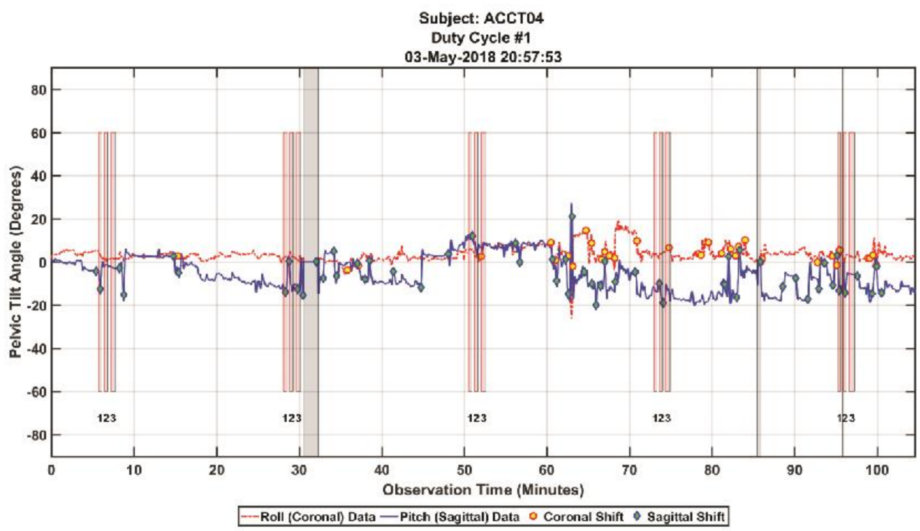
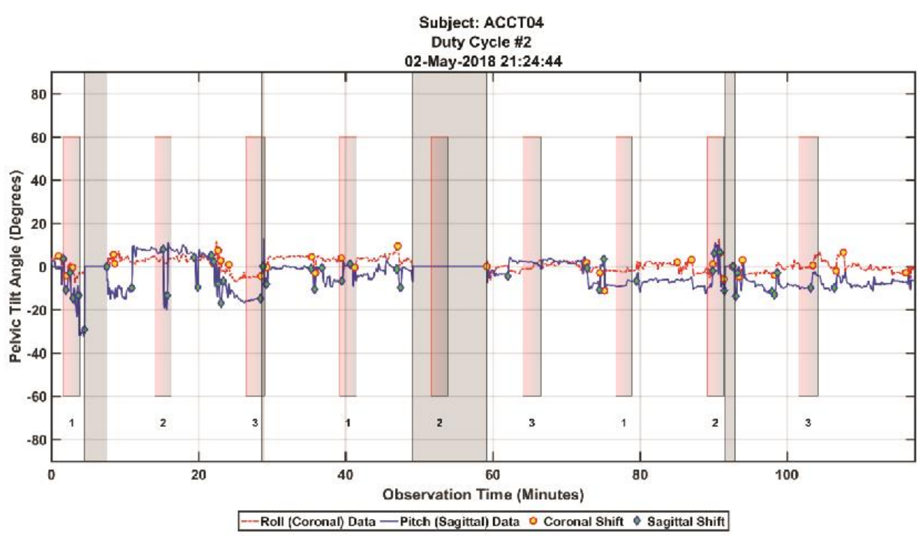
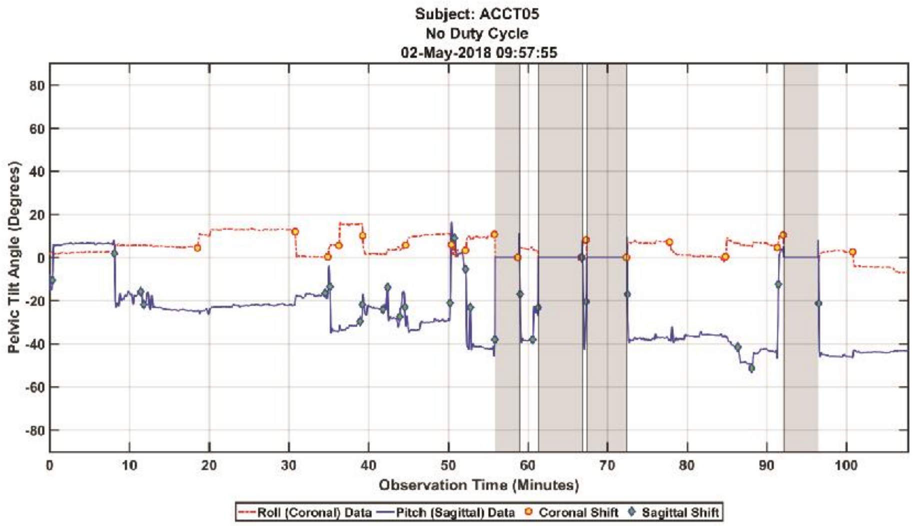
Observation Time (Minutes)
Roll (Coronal) Data
Pitch (Sagittal) Data
Coronal Shift
Sagittal Shift



Subject: ACCT04
Duty Cycle #1
03-May-2018 20:57:53
Pelvic Tilt Angle (Degrees)
Observation Time (Minutes)
Roll (Coronal) Data
Pitch (Sagittal) Data
Coronal Shift
Sagittal Shift



Subject: ACCT04
Duty Cycle #2
02-May-2018 21:24:44
Pelvic Tilt Angle (Degrees)
Observation Time (Minutes)
Roll (Coronal) Data
Pitch (Sagittal) Data
Coronal Shift
Sagittal Shift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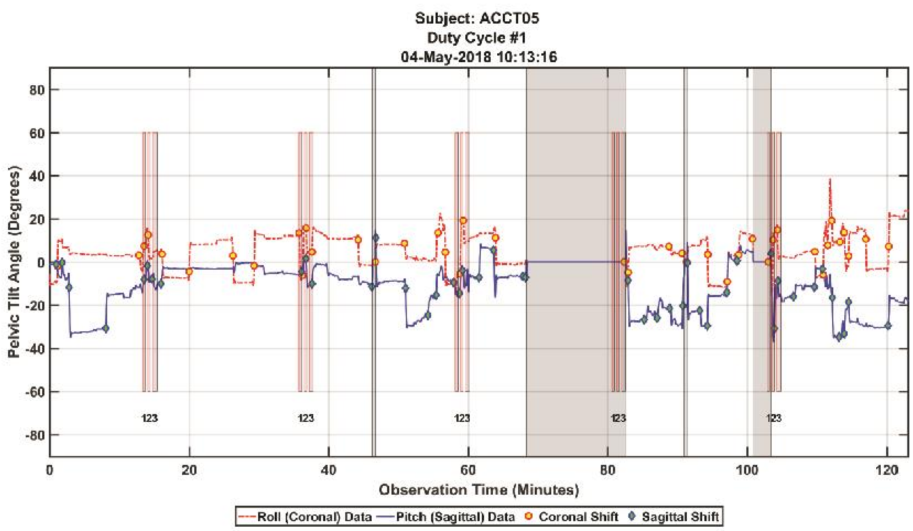
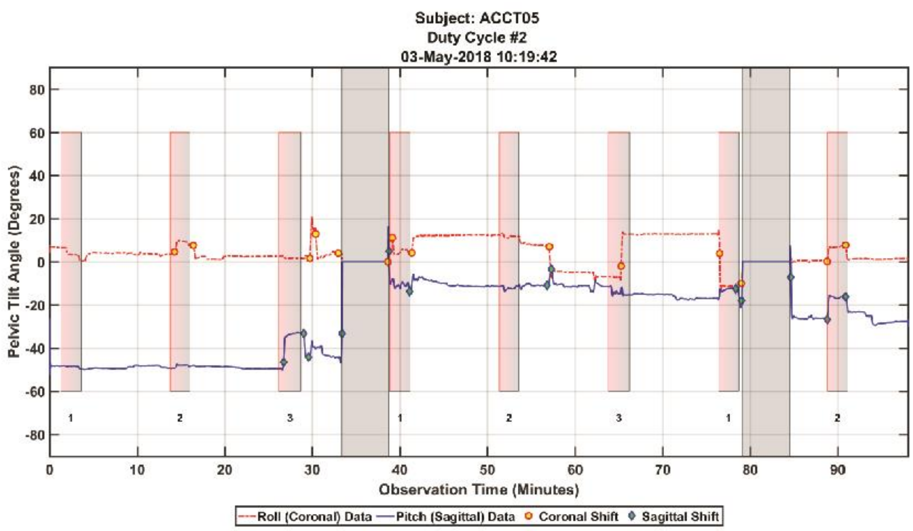
No Duty Cycle
02-May-2018 09:57:55
Pelvic Tilt Angle (Degrees)
Observation Time (Minutes)
Roll (Coronal) Data
Pitch (Sagittal) Data
Coronal Shift
Sagittal Shift


Subject: ACCT05
Duty Cycle #1
04-May-2018 10:13:16
Pelvic Tilt Angle (Degrees)
Observation Time (Minutes)
Roll (Coronal) Data
Pitch (Sagittal) Data
Coronal Shift
Sagittal Shift


Subject: ACCT05
Duty Cycle #2
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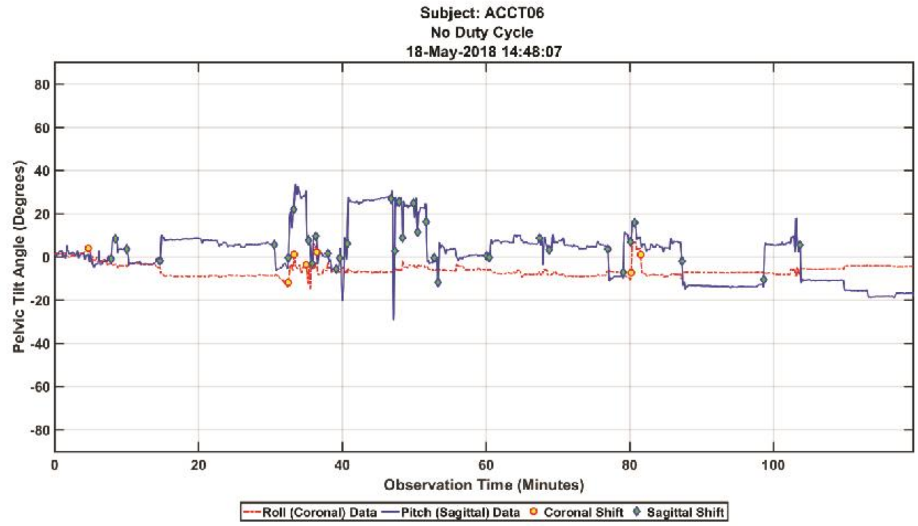
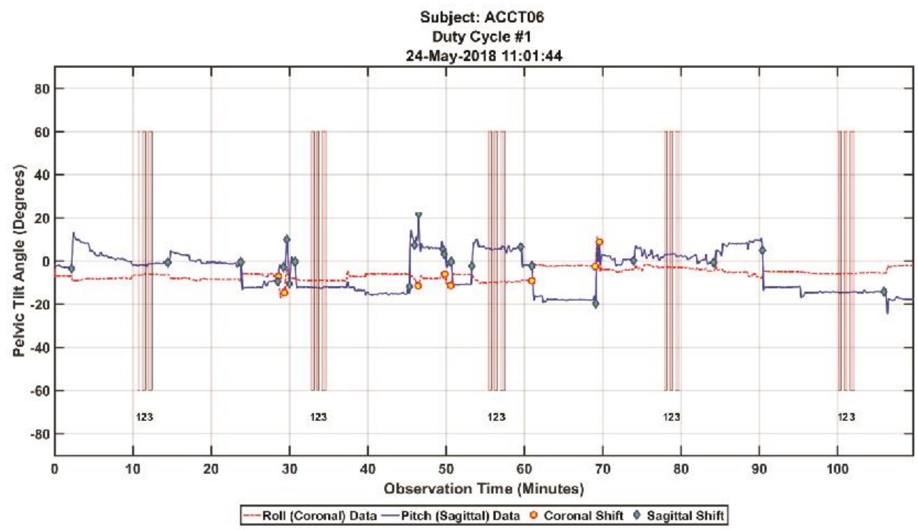
Pelvic Tilt Angle (Degrees)
Observation Time (Minutes)
Roll (Coronal) Data
Pitch (Sagittal) Data
Coronal Shift
Sagittal Shift


Subject: ACCT06
No Duty Cycle
18-May-2018 14:48:07
Pelvic Tilt Angle (Degrees)
Observation Time (Minutes)
Roll (Coronal) Data
Pitch (Sagittal) Data
Coronal Shift
Sagittal Shift


Subject: ACCT06
Duty Cycle #1
24-May-2018 11:01:44
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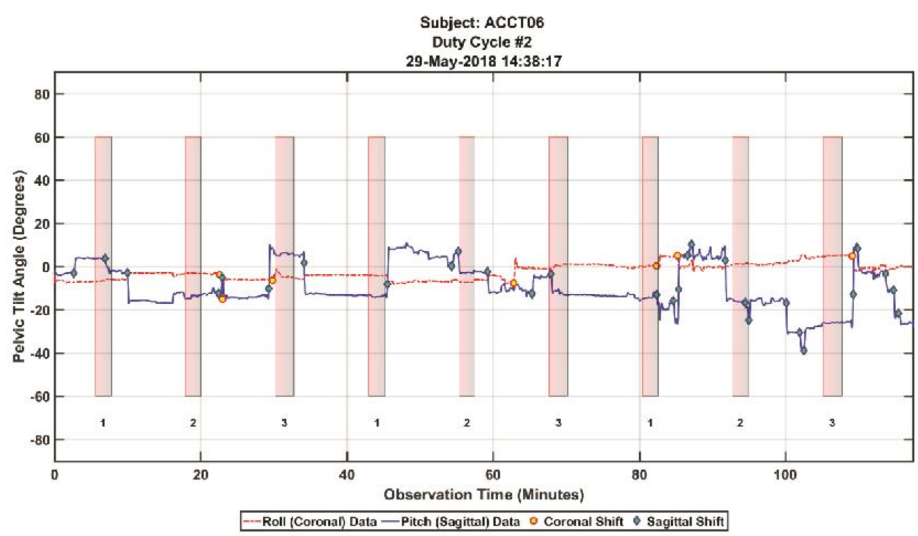
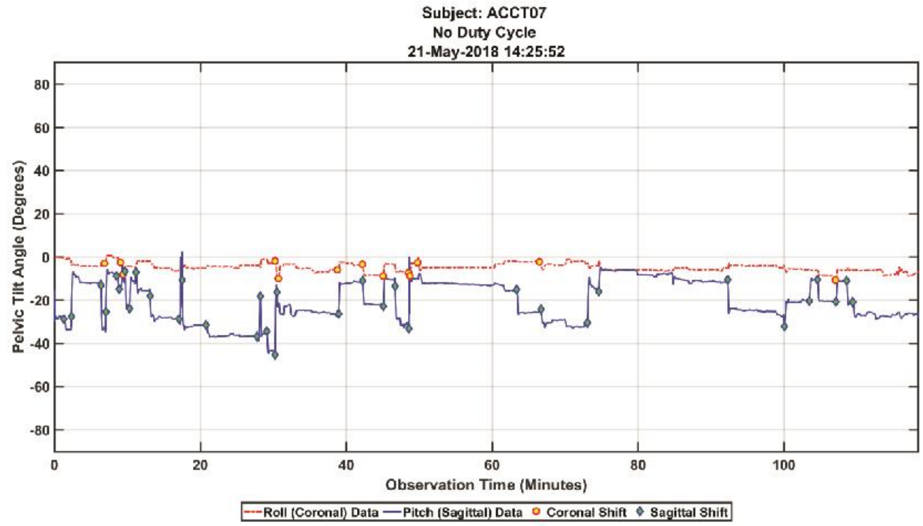
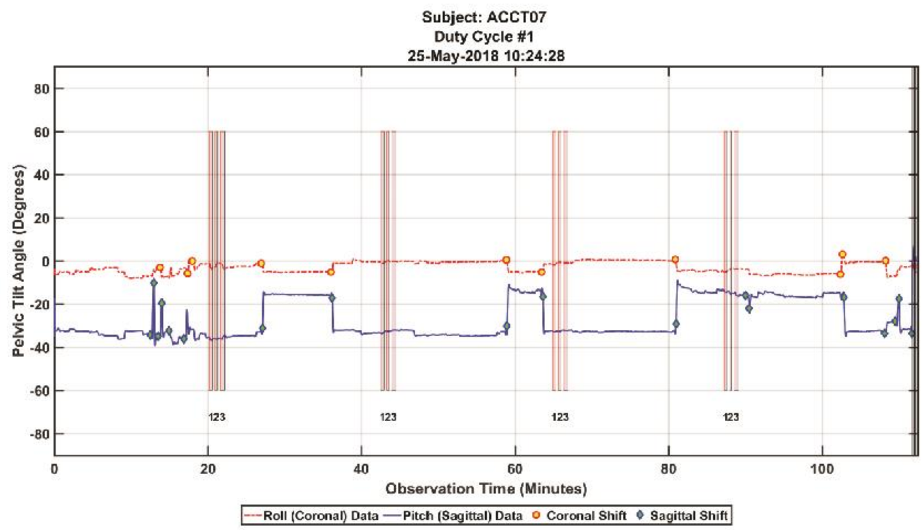
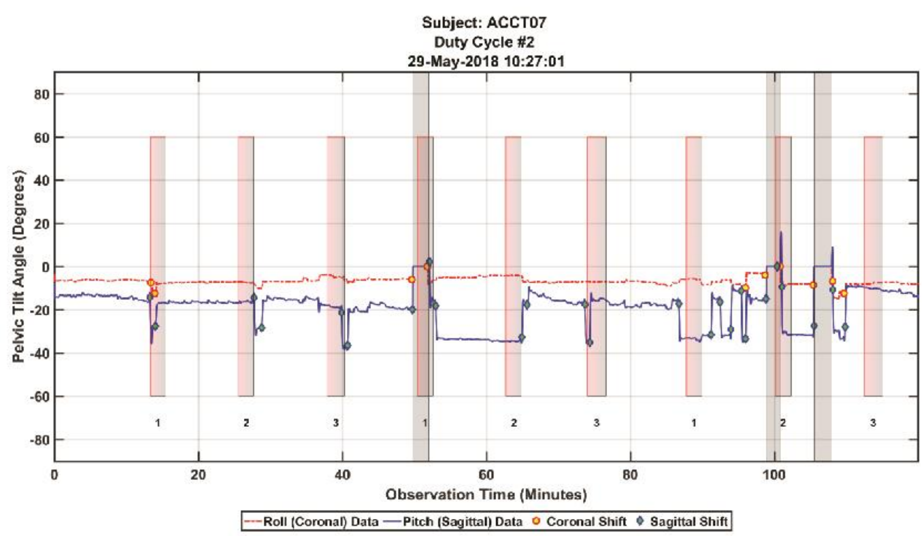
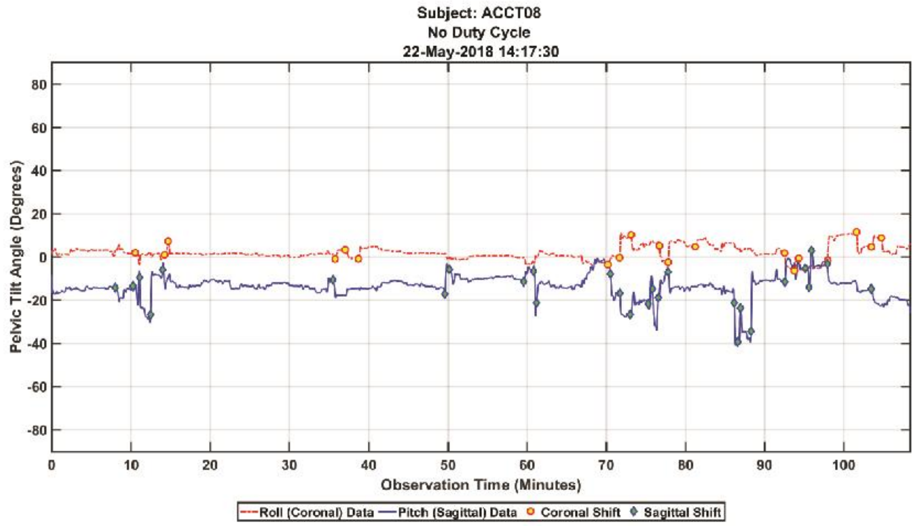
Observation Time (Minutes)
Roll (Coronal) Data
Pitch (Sagittal) Data
Coronal Shift
Sagittal Shift

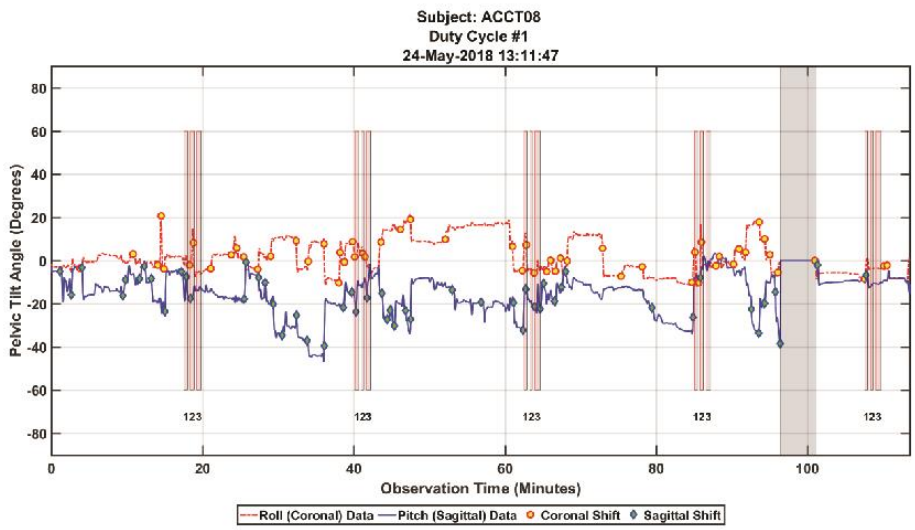

Subject: ACCT06
Duty Cycle #2
29-May-2018 14:38:17
Pelvic Tilt Angle (Degrees)
Observation Time (Minutes)
Roll (Coronal) Data
Pitch (Sagittal) Data
Coronal Shift
Sagittal Shift


Subject: ACCT07
No Duty Cycle
21-May-2018 14:25:52
Pelvic Tilt Angle (Degrees)
Observation Time (Minutes)
Roll (Coronal) Data
Pitch (Sagittal) Data
Coronal Shift
Sagittal Shift


Subject: ACCT07
Duty Cycle #1
25-May-2018 10:24:28
Pelvic Tilt Angle (Degrees)
Observation Time (Minutes)
Roll (Coronal) Data
Pitch (Sagittal) Data
Coronal Shift
Sagittal Shift


Subject: ACCT07
Duty Cycle #2
29-May-2018 10:27:01
Pelvic Tilt Angle (Degrees)
Observation Time (Minutes)
Roll (Coronal) Data
Pitch (Sagittal) Data
Coronal Shift
Sagittal Shift


Subject: ACCT08
No Duty Cycle
22-May-2018 14:17:30
Pelvic Tilt Angle (Degrees)
Observation Time (Minutes)
Roll (Coronal) Data
Pitch (Sagittal) Data
Coronal Shift
Sagittal Shift


Subject: ACCT08
Duty Cycle #1
24-May-2018 13:11:47
Pelvic Tilt Angle (Degrees)
Observation Time (Minutes)
Roll (Coronal) Data
Pitch (Sagittal) Data
Coronal Shift
Sagittal Shift

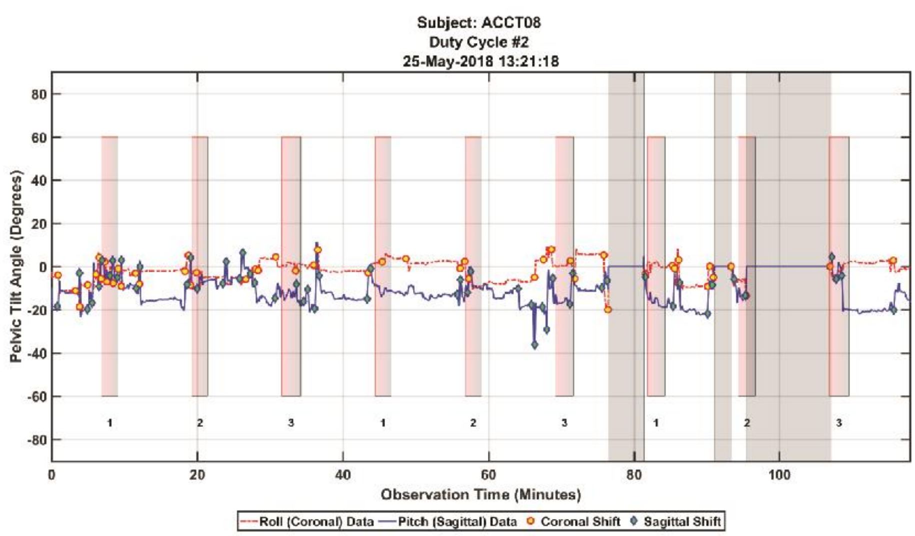

Subject: ACCT08
Duty Cycle #2
25-May-2018 13:21:18
Pelvic Tilt Angle (Degrees)
Observation Time (Minutes)
Roll (Coronal) Data
Pitch (Sagittal) Data
Coronal Shift
Sagittal Shift

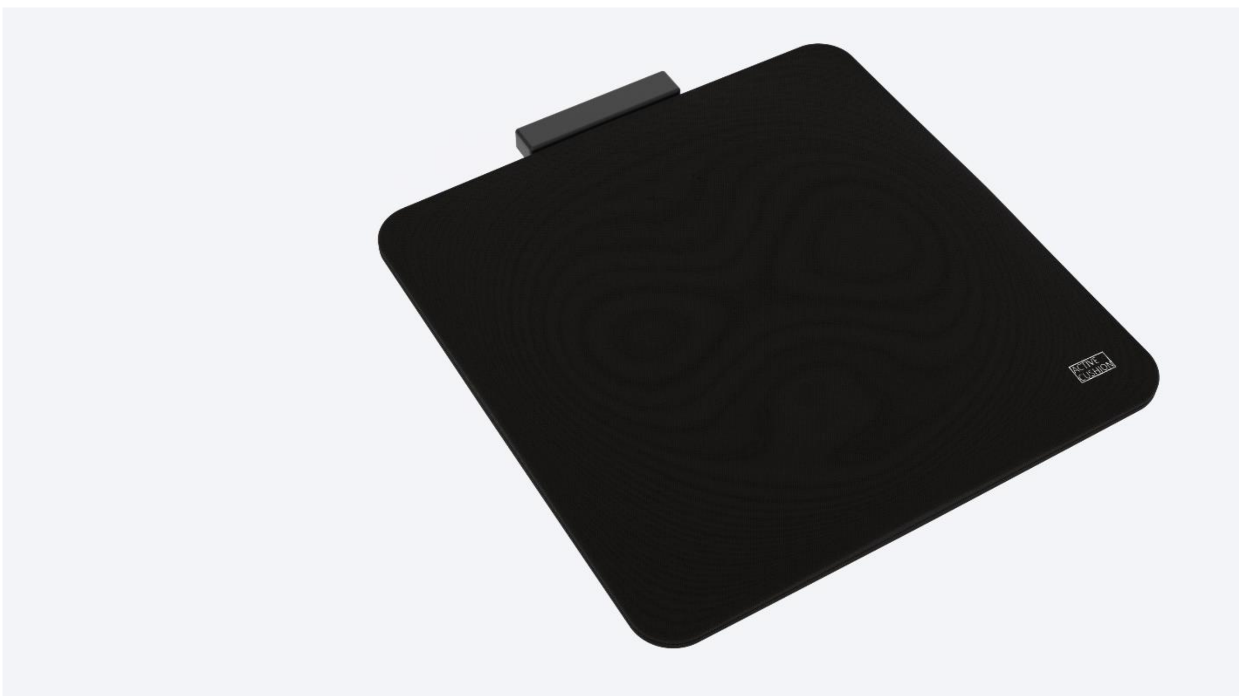
Table: Summary of the relationship between shifts and inflation

DutyCycle1	inflation1		inflation2		inflation3		inflation4		inflation5	
shift	Coronal	Sagittal	Coronal	Sagittal	Coronal	Sagittal	Coronal	Sagittal	Coronal	Sagittal
Sub#1	4	4	1	2	1	2	2	2	2	4
Sub#2	0	2	1	3	0	2	0	1	0	3
Sub#3	0	0	\	\	0	0	2	2	\	\
Sub#4	0	1	0	3	1	1	1	2	2	4
Sub#5	2	4	4	3	2	2	\	\	3	3
Sub#6	0	0	0	0	0	0	0	0	0	0
Sub#7	0	0	0	0	0	0	0	0	0	0
Sub#8	2	2	3	2	3	4	4	1	1	1
				Total inflation		37	Rection	25	Rate	67.56757

DutyCycle2	inflation1		inflation2		inflation3		inflation4		inflation5		inflation6		inflation7		inflation8		inflation9	
shift	Coronal	Sagittal	Coronal	Sagittal	Coronal	Sagittal	Coronal	Sagittal	Coronal	Sagittal	Coronal	Sagittal	Coronal	Sagittal	Coronal	Sagittal	Coronal	Sagittal
Sub#1	3	1	2	2	2	3	3	2	1	1	2	2	5	4	4	5	2	3
Sub#2	0	2	0	4	3	0	0	0	1	0	0	1	0	1	0	0	1	0
Sub#3	0	0	3	4	0	1	0	0	0	0	1	1	0	2	0	1	\	\
Sub#4	3	5	0	2	1	2	2	2	\	\	0	0	0	0	2	4	1	1
Sub#5	0	0	1	0	0	2	3	2	0	0	1	0	2	2	2	2	\	\
Sub#6	0	1	0	0	1	0	0	1	0	1	0	1	0	2	0	0	\	\
Sub#7	2	2	0	1	0	1	\	\	0	1	0	1	0	0	\	\	0	0
Sub#8	5	4	2	2	1	1	1	0	2	2	1	2	1	1	\	\	1	3
												Total inflation		65	Rection	52	Rate	80

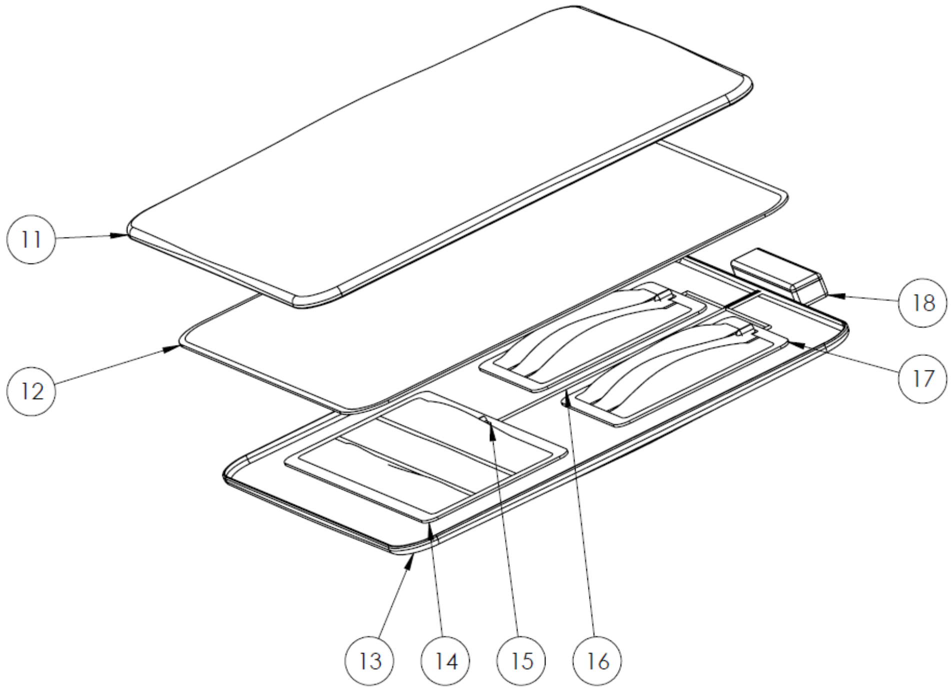
This figure shows the movement of the subjects during the bladder active time. "\" means the subject left the seat during the inflation. Each number means the specific type of shifts performed by the subjects.

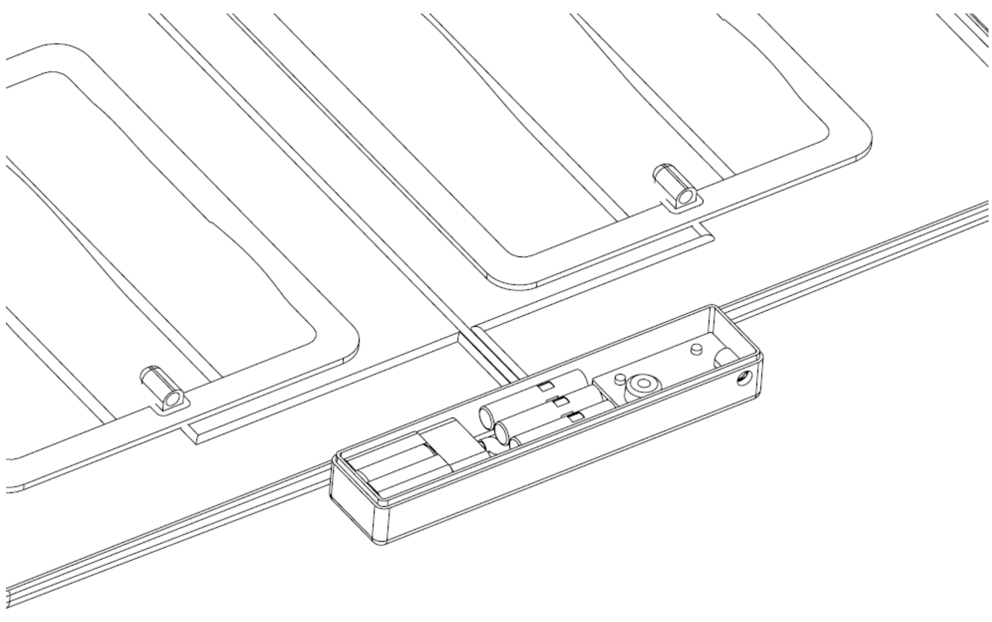
APPENDIX I. RENDERING OF THE FINAL PRODUCT

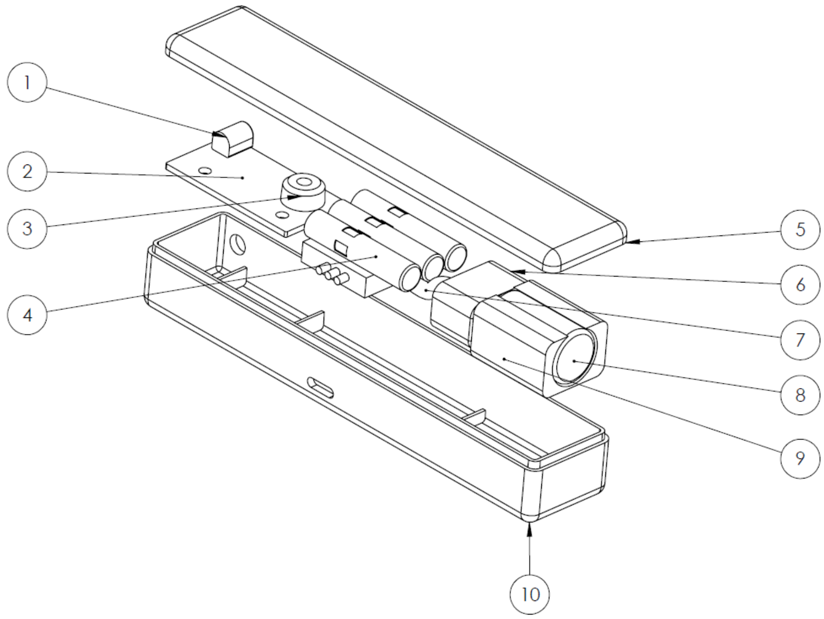



ACTIVE
CUSHION

APPENDIX J. ASSEMBLY OF THE PRODUCTS






1
2
3
4
5
6
7
8
9
10

No.	Name	Material	Model	Qty.	Price/ US	Price/Alibaba
1	Power adapter		12V 1A Triad Magnetics WSU120-1000	1	4.59	2.19
2	PCB		Customized PCB	1	\	\
3	Pressure sensor		KP229E3111XTMA1 20kpa-300kpa	1	3.5	0.85
4	Solenoid Valve		LHDB1242115H The Lee company	3	42.31	\
5	Control box Top	ABS		1	\	0.2
6	Air Pump		DC vacuum inflate Blood pressure air pump Model No. MDAP-3-05-05 Ningbo Marshine Power Technology Co. Ltd	1	\	2.59
7	Tube	PVC	4*6mm, clear, vinyl	1	\	0.4
8	Motor		See as the air pump	1	\	\
9	Noise cancellation	Foam	Density : 1.8 , 44lb compression	1	\	0.2
10	Control box Bottom	ABS		1	\	0.2
11	Cushion Top Cover	Space foam		1	\	0.74
12	Cushion base	Polymer Gel	AliGel pads	1	41	22.93
13	Cushion Bottom Cover	Space foam		1	\	\
14	Thigh bladder	TPU	Seattle fabrics	1	\	1.5
15	Air input	PVC	Kabar manufacturing	3	0.1	\
16	Tube	PVC		1	\	\
17	Buttock bladder	TPU	Seattle fabrics	2	\	\
18	Control Box		\	1	\	\
				Total	182.15	159.03

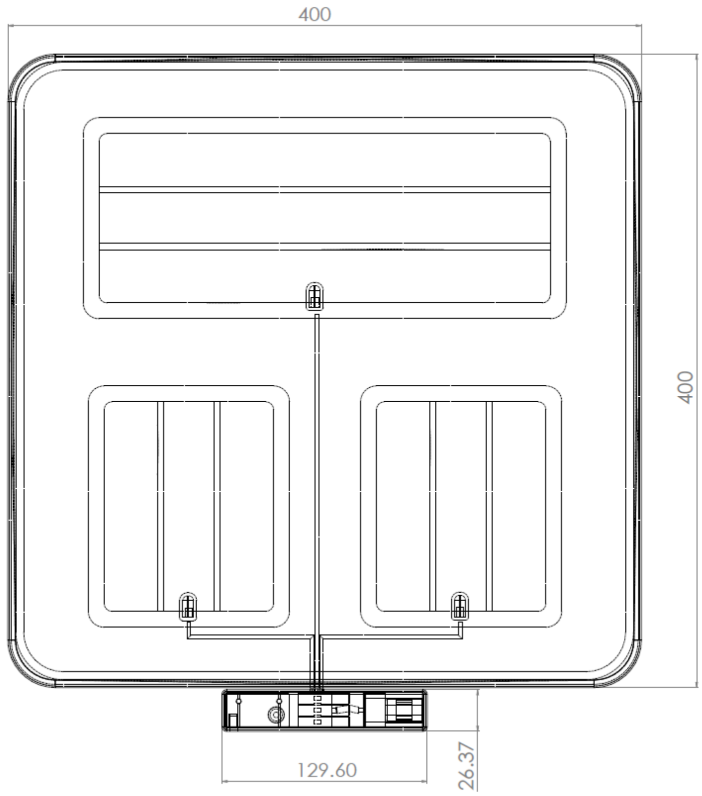


Figure 43 - Dimension of the cushion

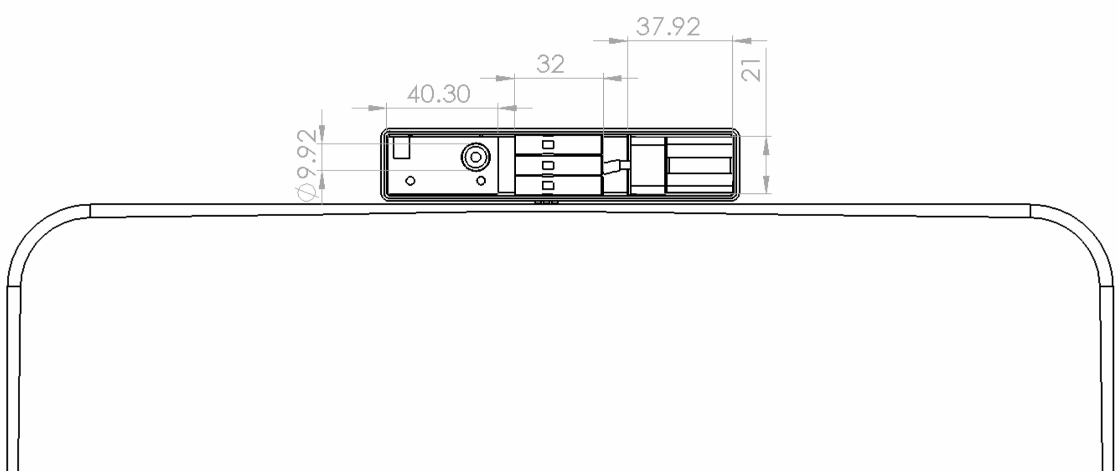


Figure 44 - Dimension of the control box

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